Chronometers and Chronometry on British Voyages of Exploration, 1819-1836

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Declaration

I declare that this thesis has been composed by myself and that no part of this thesis has been submitted for any other degree of qualification. The work described is my own unless otherwise stated.

Emily Jane Akkermans

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Dedication

In memory of my father, Frans Akkermans

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Abstract

This thesis demonstrates how a historical geography of the chronometer can inform our understanding of the production and circulation of scientific knowledge at sea. The history and development of the marine chronometer has been a topic of considerable research. Yet few studies have focused on their actual use at sea, particularly during the first half of the nineteenth century. This thesis aims to understand how officers, charged with the use and care of chronometers at sea, took up the use of these instruments and developed practices for the purpose of determining longitude at sea that would later become widespread. The thesis draws upon work in the history and historical geography of science and the history of technology and of navigational instruments to provide the context to its detailed empirical content. The thesis examines the use of chronometers on Royal Navy vessels by considering four detailed case studies of voyages and navigational practice between 1819 and 1836. These are William Edward Parry's three attempts to find a North-West Passage; William Owen's survey of the east coast of Africa, Henry Foster's scientific expedition in the Atlantic and Robert Fitzroy's survey of South America and circumnavigation. The research presents a detailed analysis of a broad range of archival material, including navigational notebooks, chronometric data books, journals, correspondence, published travel narratives and navigational manuals.

The thesis pays attention to the social and institutional networks in which the users of these instruments operated, including a consideration of the role of the State, the Royal Society and the Admiralty. It considers how reforms within the Royal Navy during this period shaped the role of naval officers, who turned to scientific pursuits to further their naval careers and to their close associations with scientific societies. The thesis argues that we should not consider 'longitude by chronometer' as a single instrumental measurement easily achieved, but, rather as a complex interaction of instruments and methods whose manipulation invoked questions of credibility and tolerance, in the instruments and in their users. By learning and adopting observatory techniques, officers integrated chronometers and astronomical techniques into established practices of navigation. This was not achieved through straightforward textbook instruction: these skills were learnt at sea, with the help of skilled astronomers. This thesis shows that techniques of data management were transported from the observatory to the ship between ship and shore. The Royal Observatory at Greenwich aided the emergence of standardised systems of numerical reduction that were required when using large numbers of chronometers and in order to 'test' one device against the another.

The thesis contributes to the history of the chronometer, the history of navigation and the history of exploration by considering how this particular instrument was used on particular voyages and how its use was shaped by the navigational practices of naval men, the aims and ambitions of astronomers, and by the limitations of the instruments themselves. The methodology pursued through the detailed examination of observational records and data workbooks affords significant new insights in the practice of science at sea in the early nineteenth century and shows how navigational knowledge derived from chronometers was constructed through agreement and negotiation.

Lay Summary

This thesis examines the use of chronometers in the early nineteenth century. Chronometers, or marine timekeepers, were specifically designed to provide accurate timekeeping at sea to assist in the determination of longitude. Scholars have examined these instruments at the point of their invention and their technical development, and have examined the first voyages that were charged with testing these instruments on board ship. Little is known, however, about how chronometers were used in the Royal Navy in the early nineteenth century, specifically between 1820 and 1850, a period in which chronometers were considered to have become widespread in use.

This research examines the practices that were adopted by Royal Navy officers in the use and management of chronometers at sea. It does so by considering four scientific expeditions that took place between 1819 and 1836. Due to their complicated and delicate mechanisms, chronometers were inherently temperamental and unreliable devices and they responded in different ways to the unstable environment of the ship. Despite this, officers were required to use them to take and record reliable navigational and longitude measurements at sea. Part of their use thus involved the management of the instruments on board ship, the training of officers in the astronomical and mathematical concepts and procedures that underlined their use, and instructions in how to record and manage the data that chronometers produced. The thesis shows that these practices differed as some officers, who were offered command of prestigious voyages, were issued with what were considered the best chronometers, ones that had been quality tested by the Astronomer Royal at the Royal Observatory in Greenwich. Other officers had to make do with what were considered 'less' good instruments and, because of this, paid more attention to their management and use. In addition, some officers were better versed in astronomy and mathematics, and

therefore trusted to receive and make use of these instruments while other officers were not.

This thesis shows that the use of chronometers remained difficult even when multiple chronometers were used to measure longitude. As a result, chronometers were used alongside astronomical methods of finding longitude, notably astronomical observations made on shore. The Admiralty Hydrographer would then evaluate the longitudes determined by these officers and select those considered more accurate in order to compile the list of latitudes and longitudes of ports around the globe. These important lists in turn helped officers using chronometers to check if their devices were working properly, as the longitude of the port listed could confirm the longitude measured by the chronometer. The use of chronometers at sea helped in the construction of a global grid of reference points for longitude.

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> The chief desideratum unquestionably is, that many ships in his majesty's service *should* be supplied with at least one good chronometer.[1]

Introduction

This statement, by Royal Navy Captain Basil Hall (1788-1844), captures the state of nautical chronometry in 1820. In a 10-page memorandum entitled, 'On the most effectual mode of supplying the navy with Chronometers', Hall urged the Admiralty to support the supply of chronometers to HM vessels, to establish depots at British ports, and to cultivate more scientific habits among officers navigating ships. By this time, the Admiralty had increased its stock of chronometers for use by the Royal Navy, but they were only issued to a few ships. Basil Hall, like others, considered chronometers beneficial to navigation and worked to promote their more widespread use at sea. His statement also alludes to the central concerns of this thesis. Why were all ships not issued with what was considered an important tool in navigation? What defined a 'good chronometer'? How did officers judge whether or not they had a good chronometer and what did they do if they did not? Why was this particular captain advocating their use?

This thesis aims to contribute to the history of the chronometer and of chronometry by examining its deployment as a situated practice, something used by particular people for specific aims. The research is informed by a number of fields of study as well as by the examination in detail of various archival holdings and ships records. It draws on work in

[1] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956. My Emphasis

historical geography on the 'production, circulation, embodiment and governance of science'.[2] It is also situated within the history of science and of technology, in the latter case relating to the provision and use of instruments of navigation. The central theme I take from these disciplines in what follows is a focus on the place of science: where science was performed and how this affected how it was conducted.[3] Chronometers were used on ships, in observatories and on shore: these form the places of science which this thesis explores. Yet, science is also informed by its political and institutional context. Alongside this, my focus is on use. I take up David Edgerton's suggestion that 'invention, "technological change" and the "shaping of technology"' should not be the central questions for the history of technology, but rather, what happens as technologies are adopted. Here, the user, rather than the inventor or developer, plays the central role.[4] It is with issues of use – of chronometers at sea, on shore, in the hands of the experienced and the more novice sailor – that this thesis is concerned.

The principal research aims

Chronometers went to sea during the late-eighteenth century to aid in the determination of longitude at sea. In time, they would become a standard navigational tool until their replacement by the widespread adoption of satellite navigation systems such as GPS in the 1990s.[5] Several scholars have examined the early conception and development of

[2] Felix Driver, 'Research in Historical Geography and in the History and Philosophy of Geography in the UK, 2001-2011: An Overview', *Journal of Historical Geography*, 42, (2013), p. 204

[3] Adi Ophir and Steven Shapin, 'The Place of Knowledge: A Methodological Survey', *Science in Context*, 4, (1991), pp. 3-21; Thomas Gieryn, 'Three truth-spots', *Journal of the History of the Behavioural Sciences*, 38, (2002), p. 113

[4] David Edgerton, *The Shock of the Old, Technology and Global History Since 1900'*, (London: Profile Books Ltd, 2008), p. 211

[5] Jonathan Betts, *Marine Chronometers at Greenwich, A Catalogue of Marine Chronometers at the National Maritime Museum, Greenwich*, (Oxford: Oxford University Press, 2017), pp. 66-72

chronometers from the late-eighteenth century.[6] For Jonathan Betts, '[by] the early 1820s, the marine chronometer had effectively come of age; even the Board of Longitude and the Royal Navy were now finally beginning to accept that it was the wholly practicable solution they had been looking for. The instrument had become standard issue to all Royal Navy vessels sent on voyages of exploration, but there was also now more regular demand for good chronometers, not just for scientific expeditions'.[7] 'By the middle of the [nineteenth] century', Betts continued, 'the use of chronometers on board ocean-going vessels was almost universal'.[8] The period between 1820 and 1850 is commonly identified as the one in which chronometers went from being a scientific instrument on board voyages of exploration to a standard tool in navigation.[9] However, while this can be claimed as an important period in the history of the chronometer, it seems odd that their use at sea in this period has not been the subject of detailed study.

This thesis examines how specific practices on Royal Navy expeditions between 1819 and 1836 played a significant role in the development of chronometric practices at sea. The principal aim of this thesis is to investigate how chronometers were used on board Royal Navy vessels by examining the chronometric shipboard practices through four detailed case studies. These are, first, William Edward Parry's three expeditions in search of a North-West Passage, on board HMS *Hecla* and HMS *Griper* 1819-1820, HMS *Fury* and HMS *Hecla* 1821-1823, and HMS *Hecla* and HMS *Fury* 1824-1825; second, William Fitzwilliam Owen's survey of the East African coast in command of HMS *Leven* and HMS *Barracouta* 1821-1826; third,

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[6] Rupert T. Gould, *The Marine Chronometer: Its History and Development*, (Woodbridge: The Antique Collectors' Club, 2013); Betts, *Marine Chronometers at Greenwich*, pp. 3-72; Alan Davies, 'The Life and Death of a Scientific Instrument: The Marine Chronometer, 1770-1920', *Annals of Science*, 35, (1978), pp. 509-525

[7] Betts, *Marine Chronometers at Greenwich*, p. 59

[8] Ibid, p. 59

[9] William E. May, *A History of Marine Navigation*, (Henley-on-Thames: G. T. Foulis & Co Ltd), 1973; Jim Bennett, *Navigation, a Very Short Introduction*, (Oxford: Oxford University Press, 2017), pp. 88-89; Gould, *The Marine Chronometer: Its History and Development*, p. 131

Henry Foster's British Naval Expedition to the South Atlantic on HMS *Chanticleer* 1828-1831; and, lastly, Robert Fitzroy's survey of South America and circumnavigation on HMS *Beagle* 1831-1836. The choice of case studies was in an important sense guided by the existence of the chronometers from these voyages within the collections of Royal Museums Greenwich (RMG). The RMG collection consists of over 200 marine timekeepers, for, the majority of which the service history of the instrument is unknown. Of the roughly 68 chronometers that were known with certainty to be employed in the period 1820-1850, only about 30 can be traced back to the captains of the ships to whom they were issued. Even when this service history is known, this does not mean that the documents associated with the captain or ship have survived, and even if they do, that the records necessarily relate to matters of chronometry at sea. The case studies here were selected because of the 'thickness' of the archival sources; that is, the existence of both the chronometer and of substantial documentation relating to its use in the collections of RMG and other repositories. This research therefore contributes to the material culture of science and technology by using it 'as both subject and source' of the thesis.[10]

The early nineteenth century was a period of naval reform. The Navy that emerged from the end of the Napoleonic Wars after 1815 had to adapt to a period of severe retrenchment and a new economy. Between 1806 and 1816, many of the Navy Boards were dissolved and the Navy and Victualling Boards were abolished in 1832.[11] With the cessation of war-time activities, John Barrow, Second Secretary to the Admiralty and Council member of the Royal Society, advocated a series of state-sponsored scientific expeditions.[12] As Don

[10] Richard Dunn, 'Material Culture in the History of Science: Case Studies from the National Maritime Museum', *British Society for the History of Science,* 42, (2009), pp. 31-33
[11] Don Leggett and James Davey, 'Introduction: Expertise and Authority in the Royal Navy, 1800-1945', *Journal for Maritime Research*, 16, (2014), p. 3
[12] John Gascoigne, *Science and the State: From the Scientific Revolution to World War*, (Cambridge: Cambridge University Press, 2019), pp. 84-92

Leggett described it, the 'period from 1800 to 1945 saw the emergence of new forms of expertise, a growth in the power of many types of specialist and a large number of bureaucratic reforms dealing with how the Admiralty functioned'.[13] The research is thus situated in this period of naval reform, following the chronometers on board these state-sponsored expeditions. Scientific societies were also undergoing change. The Royal Society was long the dominant scientific institution for British science but new, specialist societies were beginning to emerge. These included the Geological Society (1807), the Astronomical Society (1820), the Geographical Society (1830) and the British Association for the Advancement of Science (1831). The Board of Longitude, which grew out of the Longitude Act of 1714, was disbanded in 1828 and its 'duties continued by the Resident Committee that replaced it'.[14] By doing so, 'the Admiralty retained [power] in the patronage of scientific work'.[15] As I show here, it is important to consider Admiralty patronage in relation to the testing and issuing of chronometers on these voyages since the early development of the chronometer owed greatly to the work of the Board of Longitude, which, alongside the Royal Society, also supplied training and instruction.

It is important to state that this research into the use of chronometers does not take their use for granted. I hope, rather, to consider how users were trained to 'manipulate technology' and to ask questions about the 'rise of method in science' and how this depended on instructive guides.[16] One of the key themes examined is thus how officers were trained to use these instruments and what instructive literature was available to them. I do not assume that such textual guides were either necessarily definitive or unchanging. Rather

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[13] Leggett and Davey, 'Introduction', p. 3
[14] Sophie Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, Unpublished PhD, University of Cambridge, (2014), p. 182
[15] Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 215
[16] Fraser MacDonald and Charles W. J. Withers, 'Introduction: Geography, Technology and Instruments of Exploration', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), quotes on p. 9 and p. 7 respectively

than assuming that officers followed such instructions to the letter, I ask how they may have engaged with, learned from, and even influenced the relevant guides.

The status of an instrument is equally important, by which I mean its manufacturer and its association with certain qualities in its making and use. In this context, part of the research involves knowing whether users trusted the instruments used to generate navigational data, and what happened if they did not. This involves understanding the instrument's status: was it considered reliable? If not, how did users deal with uncertainty? How did users work with chronometers that may not have functioned as they should? How and where were they installed on the ship? Who was allowed access to them? What skills were required to use them? How much knowledge did one require of the astronomical concepts underpinning the various methods then current in establishing longitude at sea? What happened when an instrument was suspected of performing poorly, or even failing? And how was 'failure' judged? These questions bring into focus the epistemological standing of the instruments *and* the data they produced and they point to questions of credibility and authority in their users.

Chronometers did not work in isolation. Recent work has shown how old and new navigational techniques were used in conjunction with each other.[17] New methods were trialled and developed at sea where the 'possibilities and requirements of accuracy were always contingent'.[18] This thesis examines how chronometers were used alongside other navigational techniques, old and new. In this period, navigational science increasingly involved astronomical and mathematical techniques which produced large quantities of data that required comparison and calibration. Even as it is essential to the use of chronometers,

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[17] Richard Dunn and Rebekah Higgitt, 'Introduction', in: *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds. (Basingstoke: Palgrave Macmillan, 2016), p. 4

[18] Dunn and Higgitt, 'Introduction', in: *Navigational Enterprises in Europe and its Empires, 1730-1850*, p. 7

the role of mathematics and of mathematical calculation in particular is often overlooked in chronometric histories. By drawing attention in what follows 'to techniques for managing numbers', I hope to shed light on how mathematical observational techniques were developed alongside and became embedded within navigational shipboard practices.[19] I hope to show how this data was collected and organised by participants and how it related to other data collected at sea and at other sites.

A note on the primary source material

Research in historical geography and in much history of science relies on primary source material for its 'ethical and epistemological credibility'.[20] Archival research in a sense is the 'fieldwork' of historical scholarship. While we have a range of records on the presence of chronometers at sea and upon the validity of the resultant data, there is, in general, a lack of primary sources relating to their actual *use* at sea. Nockolds noted this limitation in the 1960s, emphasising the scarcity of extant records which provide evidence of chronometric practices and how this absence had limited research into the 'general adoption of the method'.[21] It is possible, however, to determine the nature of chronometers' use at sea by working from the artefact itself in association with materials held within various national and international repositories.

My research focuses on documents that were initially produced by and for the State and its institutions, such as the Admiralty, the Board of Longitude, the Royal Society and the Hydrographic Office. What remains of relevant navigational documents is spread over a

[19] David Aubin, Charlotte Bigg and H. Otto Sibum, 'Introduction: Observatory Techniques in Nineteenth-Century Science and Society', in: *The Heavens on Earth, Observatories and Astronomy in Nineteenth-Century Science and Culture*, David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), p. 13
[20] Thomas Osborne, 'The Ordinariness of the Archive', *History of the Human Sciences*, 12, (1999), p. 51
[21] G. W. Nockolds, 'Early Timekeepers at Sea: The Story of the General Adoption of the Chronometer between 1770 and 1820', *Antiquarian Horology*, 4, (1963), p. 110

number of repositories. For example, Cambridge University Archives hold the Royal Greenwich Observatory Archives containing historical records dating from 1675 to *c*.1980. The main documents relevant to the thesis are among the Papers of Astronomer Royal John Pond (1811-1835) and the papers of the Board of Longitude (1737-1828), and the papers of Astronomers Royal Nevil Maskelyne (1765-1811) and George Airy (1835-1881). The National Archives holds Admiralty correspondence and administrative records of the Royal Navy such as logbooks, journals, muster lists, charts and coastal views. The correspondence and papers of Sir Edward Sabine (1788-1883) includes documents relating to his use of chronometers during his appointment as astronomer on two Arctic expeditions between 1818 and 1820. Additional material produced by Sabine is held by the Royal Society (a chronometer diary kept on board HMS *Hecla*, 1819-1820) and by the Plymouth and West Devon Record Office (Sabine Journal and letters kept on board HMS *Isabella*, 1818). The astronomical and magnetic observations of George Fisher, astronomer on Parry's second expedition (1821-1823), were collected and preserved by his relatives and now form part of the archival holdings of RMG. His journals detail the astronomical and mathematical calculations for longitude and were a valuable resource for this thesis. In addition, the collection of John Lort Stokes (1811-1885), who served as an officer on HMS *Beagle*, is held within the RMG archive. His navigational and surveying notes composed on HMS *Beagle*, although relatively limited in their scope, comprise one of the few surviving documentary sources relating to the navigational practices on that vessel. Additional manuscripts relating to the *Beagle* were consulted in the United Kingdom Hydrographic Office (UKHO) archive in Taunton. These included the *Beagle's* chronometer rate book and chronometer comparison book. In total, this is all that remains of the chronometric practices of HMS *Beagle.* In sharp contrast, the collection of documents relating to Henry Foster's (1797-1831) chronometrical practices, also at UKHO, is quite extensive and its analysis forms a significant part of this thesis. This collection, comprising astronomical data books, note books and correspondence with the Hydrographic Office provided a comprehensive overview of day-to-day shipboard practice on instrumental use. These sources have hitherto not been studied by historians of science as they consist primarily of tabulated numerical data which can only be understood in relation to other source material. For students of the routine practice of navigation in general, or of chronometers in particular, this thesis shows how such documents can be a significant and valuable resource.

In addition to the manuscript documents described above, that is, those surviving records which were produced at sea as a direct result of chronometric practices, I make use of journals, the published narratives of expeditions, correspondence, newspapers and literary journals, navigation manuals, printed chronometric instructions and committee meetings and minutes of the Admiralty, of the Board of Longitude and of the Royal Society. Where the shipboard documents produced by naval officers may tell us *how* chronometry was practised at sea, these sources may help us understand *why* these choices were made.

The structure of the thesis

Chapter 2 examines the literature on the history of the chronometer in three main areas; its technological history, its history in relation to navigation and its history in relation to maritime exploration. I then examine the disciplinary framework that has informed my research with particular reference to work in historical geography on the geographies of science, to the 'spatial turn' in the history of science and to matters of importance in the history of technology. This chapter shows how insights from recent work in these fields can inform a new approach to the study of navigational practices, specifically chronometry.

Chapter 3 considers the political and cultural networks in which the officers issued with chronometers operated. From this point, the thesis takes, if you will, a 'voyage-like' structure, working from the port, to departure, to sea-based practices, to land again. I start this voyage, on land, in order to examine the context in which officers were awarded not only the command of a vessel, but also the responsibility for the instruments they were commissioned to use. I examine the role that the Board of Longitude, the Hydrographic Office, and the Admiralty played in overseeing the stock, supply and testing of instruments prior to their purchase for Admiralty use and how they issued them to specific vessels and crews. I introduce the scientific expeditions that form the case studies which are my focus and examine the context and particular aims of each voyage, which, as I shall show, were commonly determined in collaboration with the Royal Society. The chapter also describes the inherent unreliability of the chronometers and how the notions of reliability and, thus, of accuracy, were both shaped internally (in the mechanical hardware of the instruments) and externally (in relation to the rules and regulations established for their use) and how these issues were managed by individuals on land and at sea.

Chapter 4 examines the training and instruction that was given in relation to chronometric practices. Chronometric instructions were both surprisingly few and limited in their content until the early nineteenth century. Even then, as I shall show, they were often limited to a few rules that officers should follow. I consider where and how an officer received his education and training and how this training had an impact on the practices undertaken on their expeditions. In this context, I examine what 'tacit knowledge' was required for the chronometer to work at sea, and how this was learned if not communicated by descriptions and rules in manuals or textbooks. The chapter argues that there was no standardised method or training for officers using chronometers during this period.

Chapter 5 investigates how the chronometer was managed at sea. Drawing on research which identifies problems that are inherent when travelling with instruments and trying to operate them 'on the move', I examine the structures and practices which officers put in place to ensure their instruments would perform adequately. I examine the different approaches that were used and how users adapted their working practices based on experience as well as upon more ‘formal’ training. I consider how users themselves were trained and disciplined when using chronometers, and examine the embodied skills that were required in the operation of chronometers.

Chapters 6 and 7 are similar in terms of the material examined yet different in their focus. Both chapters consider the importance and difficulties of keeping records and accounts of practice. In chapter 6, building on research emphasising the importance of the ‘circulation of things’, I examine not only how record keeping was essential for keeping track of the ship from a navigational perspective, but also how such record keeping was embedded within a complex network of instruments, observations, observers and measurements, on board and on land. In short, the practice of chronometry produced volumes of data that required continuous monitoring. I consider why particular determinations of longitude were considered accurate and others not and how users determined whether their instruments were working correctly. The focus in this chapter is particularist and localist, in placing and understanding specific onboard practices.

In chapter 7 the emphasis rests on the analysis and processing of this data. The chapter examines the output of the chronometer and how this data was incorporated into global cultures of navigation. In this chapter, the ship has returned to Britain and, once on shore, the accumulated data was analysed and processed, perhaps to be incorporated into revised versions of textual instruction. My analysis is informed by the idea of negotiation and agreement in science and through cycles of knowledge. Chronometers were used alongside other methods for determining longitude, whether ship- or land-based practices. The chapter takes into account other places of knowledge crucial for chronometry, and so draws ‘attention to place and to the connections between places’.[22] In this final empirical chapter, I consider how a ‘cycle of navigational accumulation’ has been completed. Data has been collected on board ship, where an initial weeding took place. Through further mathematical work, the data was organised and reduced to become manageable. Finally, the data was processed at the Hydrographic Office where, again, it was once more collected, organised and reduced. Once it was assessed in relation to other data and placed in the context of the instructions and purpose of a subsequent voyage, the data was stabilised and could be sent out on voyage again.

[22] Charles W. J. Withers, ‘Place and the “Spatial Turn” in Geography and in History’, *Journal of the History of Ideas*, 70, (2009), p. 658

2

Chronometry at Sea: The Research Context

> When lunar observations & chronometers were first introduced in order to determine the longitudes at sea, & even for many years afterwards, it was the practice of seamen to hold these methods in contempt; but this unworthy feeling gradually gave way to a more enlightened spirit, & in the present day we see officers of all ranks, taking a pride and satisfaction not only in availing themselves of the methods alluded to, but in following up a number of other liberal & scientific pursuits; connected more or less directly with their profession. This generous ardour to attain nautical & philosophical knowledge, has of late taken deep root in the navy, & seems now to want only a little judicious cultivation in order to produce the most essential public benefits.[1]

Introduction

The words above are once more from Basil Hall's 1820 memorandum to the Admiralty. Hall had by this point already spent two decades at sea in the Royal Navy. Alongside his naval career, Hall was in several ways a man of science: an author, a member of the Royal Astronomical Society. He was involved in global pendulum experiments to measure the figure of the earth and, was an advocate for 'voyages devoted to the "express purpose of research"'.[2] Hall's extract neatly describes the context in which I examine chronometry at sea in the early nineteenth century, amongst officers with an 'enlightened spirit' and following 'scientific pursuits', men who have been termed 'scientific servicemen' by historian David Phillip Miller and who contributed to the growing professionalisation of science in this period.[3]

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[1] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956

[2] Sophie Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, Unpublished PhD, University of Cambridge, (2014), p. 121

[3] David Phillip Miller, 'The Revival of the Physical Sciences in Britain, 1815-1840', *Osiris*, 2, (1986), pp. 107-134; Randolph Cock, 'Scientific Servicemen in the Royal Navy and the Professionalisation of Science 1816-1855', in *Science and Beliefs: From Natural Philosophy to Natural Science 1700-1900*, David M. Knight, and Matthew D. Eddy, eds. (Aldershot: Ashgate 2005), pp. 95–112

In this chapter, I start by examining how the history of the chronometer is currently reflected within different disciplines. The first section examines how technological, navigational and expeditionary histories situate and explore the chronometer and its development. I then turn to the literature that informs the thesis and detail how my work is placed within, and relates to, the themes discussed. Historical geographies of science study the 'production, circulation, embodiment and governance of science'.[4] I therefore examine these themes by turning, first, to how place shapes and defines scientific practices. Second, I examine how authority, credibility and trust is generated in scientific pursuits. Third, I consider how knowledge circulates, which relates closely to the fourth section on instrumentation, replication and standardisation in scientific practices. This disciplinary framework requires a different set of questions to be asked concerning chronometers and chronometric histories and puts their *use*, in the hands of naval officers, in focus.

Chronometers and chronometry explained

Technical Interpretations

Considerable research has been done to describe the technological development of the chronometer.[5] These histories discuss how the chronometer developed alongside other methods that were considered by the Board of Longitude as a means to accurately determine

[4] Felix Driver, 'Research in Historical Geography and in the History and Philosophy of Geography in the UK, 2001-2011: an Overview', *Journal of Historical Geography*, 42, (2013), p. 204; Thomas Gieryn, 'Three truth-spots', *Journal of the History of the Behavioural Sciences*, 38, (2002), p. 113; Adi Ophir and Steven Shapin, 'The Place of Knowledge: A Methodological Survey', *Science in Context*, 4, (1991), pp. 3-21

[5] Rupert T. Gould, *The Marine Chronometer, Its History and Development*, (Woodbridge: The Antique Collectors' Club, 2013); Eric Gray Forbes, 'The Origin and Development of the Marine Chronometer', *Annals of Science*, 22, (1966), pp. 1-25; William J. H. Andrewes, ed. *The Quest for Longitude*, (Harvard University: Collection of Historical Scientific Instruments, 1996); Jonathan Betts, *Marine Chronometers at Greenwich, A Catalogue of Marine Chronometers at the National Maritime Museum, Greenwich*, (Oxford: Oxford University Press, 2017); Alun Davies, 'The Life and Death of a Scientific Instrument: The Marine Chronometer, 1770-1920', *Annals of Science*, 35, (1978), pp. 509-525

longitude at sea and how they developed in the later nineteenth and twentieth centuries. Gould concluded that chronometers were a 'satisfactory solution', Betts that the chronometer was 'established as the practical means of finding longitude at sea' by the 1820s.[6] These narratives are embedded within a land-based approach from which we learn in detail about the technological development of the chronometer, the personalities of the instrument makers, the difficulties of trials and testing and issuing rewards, and the disputes that accompanied them. From these histories, we learn that the chronometer came into general use sometime between 1825 and 1850, and consider 'general use' in the sense of a being issued to ships and used in practice.[7] Quite why, and how, this occurred and with what variation within this period is not addressed. Nor does this literature discuss the experience of the navigator learning to operate these instruments.

Popular histories of the 'longitude problem' commonly focus upon the technological development of the chronometer as *the* solution to 'the longitude problem'. From this perspective, the chronometer went to sea because it straightforwardly allowed its users to determine longitude. Let us consider the terms on which success is judged in these 'chronometer-centric' histories: chronometers were successful because they were reliable and easy to use. All navigators required was the rate and error of the chronometer, which was readily found by taking Equal Altitudes of the Sun. Once error and rate were determined, they were deducted or added to the time shown on the dial and longitude was found. According to these histories, this mechanical solution was superior to complex astronomical solutions due to its simplicity.[8]

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[6] Gould, *The Marine Chronometer*, p. 117; Betts, *Marine Chronometers at Greenwich*, p. 60

[7] David S. Landes, *Revolution in Time*, (Cambridge: Harvard University Press, 2000), pp. 155-202; Nicolas A. M. Rodger, *The Command of the Ocean: A Naval History of Britain, 1649-1815*, (London: Penguin Books Ltd, 2004), pp. 382-383

[8] Dava Sobel, *Longitude: The True Story of a Lone Genius who Solved the Greatest Scientific Problem of his Time,* (London: Fourth Estate, 1996); Neil MacGregor, '91. Ship's Chronometer from HMS *Beagle*', *A History of the World in* 100 *Objects*, (New York: Viking, 2011), pp. 595-599

Navigational Interpretations

Within work in the history of navigation we learn of the art and practice of navigation, or 'the art of conducting a ship successfully from one place on the earth's surface to another'.[9] Chronometers are introduced and examined in the context of finding longitude at sea. The conclusion is similar to that in popular histories: 'the "mechanicks" had solved the problem which had defeated the scientists of generations', that is, the operation of the chronometer in the hands of its users found longitude.[10] Traditional histories of navigation focus predominantly on the development of those methods, maps and technologies that helped sailors navigate the oceans as a process of linear and sequential development.[11] If such works help illustrate the field of navigation as diverse, they do little to help understand the implementation of these new technologies from the users' or operators' points of view. The challenges of using chronometers may be noted, but how responses to those challenges developed in practice are not examined in any depth.[12] In brief, many of these works discuss the technological development of instruments of navigation, and tend to see the development of 'modern' devices such as the chronometers designed by Arnold and Earnshaw as the basis to their discussion of the many nineteenth-century examples. In such narratives, not only is the development of chronometry seen as 'simply' chronological and without reference to the conditioning social context, but the early nineteenth century is generally glossed over, treated as a period in which such chronometers as were at work were too expensive and too few in number to allow for general use.

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[9] William E. May, *A History of Marine Navigation*, (Henley-on-Thames: G T Foulis & Co Ltd, 1973), p. xiii

[10] J. E. D. Williams, *From Sails to Satellites: The Origin and Development of Navigational Science*, (Oxford: Oxford University Press, 1994), p. 107

[11] May, *A History of Marine Navigation*; Williams, *From Sails to Satellites: The Origin and Development of Navigational Science*; Charles H. Cotter, *A History of Nautical Astronomy,* (London: Hollis & Carter Ltd, 1968)

[12] May, *A History of Marine Navigation*, pp. 155-175

Other work goes into more detail about the extensive practical details involved in managing chronometers at sea. For Cotter, the questions of temperature variation, the management of the instruments, the routine of winding and the difficulties of establishing the rate and error were all aspects that required attention in a fuller history of chronometry.[13] Cotter has described the astronomical observations and procedures that were necessary for longitude to be reckoned by chronometer. Observers were required to find the local time, by solving what is known as the astronomical or PZX triangle, to which the rules of spherical trigonometry applied. There were a variety of mathematical formulae to choose from and the choice was often dependent on the particular nautical tables that the operator used. Navigators would often stick to a method they learned by rote.[14] Again, while the practice of chronometry at sea is recognised and the problems of chronometers' use noted, the solutions that were considered and implemented in practice are not examined. Jim Bennett has acknowledged this and points out that although the new methods for finding longitude were taken up at sea, their application proved problematic in practice: the 'observational and calculational techniques required for lunars had to be learnt and mastered' and in this context, rather than being a straightforwardly 'useful' technology, 'chronometers had to earn the seaman's trust and even then were very expensive'.[15]

Although several studies have examined the use of chronometers at sea, the focus has been on the late eighteenth century and upon their use in the voyages of exploration commanded by James Cook (1728-1779), John Phipps (1744-1792), George Vancouver (1757-1798), William Bligh (1754-1817), and Matthew Flinders (1774-1814), on which chronometers were trialled.[16] These voyages tested and trialled the use of the first marine

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[13] Cotter, *A History of Nautical Astronomy*, pp. 52-56
[14] Ibid, pp. 243-254
[15] Jim Bennett, *Navigation, a Very Short Introduction*, (Oxford: Oxford University Press, 2017), p. 89
[16] Derek Howse, 'Captain Cook's Marine Timekeepers, Part I: The Kendall Watches', *Antiquarian Horology*, 6:4, (1969), pp. 190-199; Derek Howse, 'Captain Cook's Marine Timekeepers, Part II: The

timekeepers by Larcum Kendall (1719-1790), John Arnold (1736-1799) and Thomas Earnshaw (1749-1829). The success of these early trials was the result of several elements in combination. The Board of Longitude played an important role in the introduction of chronometers to shipboard practices, appointed astronomers to these expeditions, and provided them with instructions.[17] Expeditionary astronomers used a wide range of astronomical techniques, both at sea and on land, to determine the error and rate of the chronometers. Davies stressed the importance of the 'tent observatory and the pendulum regulator' for making these observations on land.[18] The astronomers worked alongside experienced navigators who were skilled in traditional methods that remained essential in navigation.[19] Andrew David has shown how George Vancouver's surveys built upon a wide range of skills, resources, instruments and techniques.[20] Here, chronometers, lunar distances and dead reckoning were all techniques employed to measure distances. These methods were based on various instructions issued by the Board of Longitude and the Admiralty and evident in different navigation and surveying manuals. From the early use of chronometers, we learn that they could be a valuable instrument, provided that their rate remained stable and they did not stop. These were, however, exactly the problems that users commonly experienced. In general, these voyages tested and trialled these early chronometers and

Arnold Chronometers', *Antiquarian Horology*, 6:5, (1969), pp. 276-280; Ann Savours, '"A Very Interesting Point in Geography": The 1773 Phipps Expedition towards the North Pole', *Arctic,* 37, (1984), pp. 402-428; John Bendall, *Kendall's Longitude,* (London: Austin Macauley Publishers Ltd, 2019)

[17] Richard Dunn and Eóin Phillips, 'Of Clocks and Cats', *Antiquarian Horology*, 34, (2013), pp. 88-93

[18] Alun C. Davies, 'Horology and Navigation: The Chronometers on Vancouver's Expedition, 1791-95', *Antiquarian Horology*, 21, (1994), p. 252

[19] Jim Bennett, 'Mathematicians on Board: Introducing Lunar Distances to Life at Sea', *British Journal for the History of Science*, 52, (2019), pp. 65-83

[20] Andrew David, 'Vancouver's Survey Methods and Surveys', in: *From Maps to Metaphors: The Pacific World of George Vancouver*, Robin Fisher, ed. (Vancouver: UBC Press, 2014), pp. 51-69

attempted to identify which problems occurred and why.[21] In addition, successful use of a chronometer on such a prestigious voyage could provide good publicity for the makers.

Some studies have focused on the distribution of chronometers employed at sea.[22] May examined the early use of chronometers on East India Company (EIC) and Royal Navy vessels and also studied regulations concerning the issuing, testing and stocks of chronometers which took place on shore, as well as the regulations regarding which personnel were responsible for the instruments once on board the ship. Webb has additionally shed light on the role that the Royal Observatory and the Hydrographic Office played in regulating the testing, stock, supply and issuing of chronometers.[23] While valuable, these studies do not extend their research to consider the actual practice of chronometry at sea.

Expeditionary Interpretations

Histories of exploration tend to mention chronometers only in passing. The same conclusion can be found: 'accurate navigation also depended upon the accurate measurement of time, which was possible thanks to Harrison's invention of the marine chronometer; longitude at sea could now be determined accurately. Local time, generally noon, was determined astronomically by observing when the Sun was at its meridian, and this time could be

[21] Alun C. Davies, 'Vancouver's Chronometers', in: *From Maps to Metaphors: The Pacific World of George Vancouver*, Robin Fisher and Hugh J. M. Johnston, eds. (Vancouver: UBC Press, 2014), pp. 70-84

[22] William E. May, 'How the Chronometer Went to Sea', *Antiquarian Horology*, 9, (1976), pp. 638-663; Simon C. Davidson, 'The Use of Chronometers to Determine Longitude on East India Company Voyages', *The Mariner's Mirror*, 102:3, (2016), pp. 344-348; Simon C. Davidson, 'Marine Chronometers: The Rapid Adoption of New Technology by East India Captains in the period 1770-1792 on over 580 Voyages', *Antiquarian Horology*, 40, (2019), pp. 76-91;

[23] Adrian Webb, *The Expansion of British Naval Hydrographic Administration, 1808-1829*, Unpublished PhD, University of Exeter, (2010); Yuto Ishibashi, 'A Place for Managing Government Chronometers: Early Chronometer Service at the Royal Observatory Greenwich', *Mariner's Mirror*, 99:1, (2013), pp. 52-66

compared by the chronometer with a time at a standard location, generally Greenwich'.[24] Studies of the imperial, commercial and colonial aims of oceanic exploration commonly consider the voyages of James Cook, William Bligh, George Vancouver, Matthew Flinders and Robert Fitzroy.[25] Such work tends to concentrate on the context in which chronometers and other scientific measuring devices were used, but they do not examine those devices or their use in detail. In general, they focus on a region, a voyage, or an individual. The voyage of HMS *Beagle* is a good example, which generated considerable research largely in relation to Fitzroy's gentleman companion, Charles Darwin (1809-1882). Under the command of Robert Fitzroy (1805-1865), the *Beagle* was provisioned with twenty-two chronometers, the largest number of chronometers carried by the Royal Navy on any one vessel during this period. Despite this, the chronometric history of this voyage has been rather overlooked and the aims and implications of completing a global chain of meridian distances rather glossed over. Rather than considering the complexities of managing twenty-two chronometers, they are heralded as accurate instruments where the result of the meridian distances, established during the five years at sea, 'showed a discrepancy of only 33 seconds from the expected time'.[26]

Histories of exploration and expeditionary voyages thus often reference the invention of the chronometer and the new ways in which longitude could be measured by the nineteenth century, but because they do not address the practical implementation of these methods, they miss the difficulties faced by their users and the complexities of practice at sea.

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[24] Trevor H. Levere, *Science and the Canadian Arctic*, (Cambridge: Cambridge University Press, 1993), pp. 53-54

[25] Nigel Rigby, Pieter van der Merwe, Glyn Williams, *Pacific Exploration, Voyages of Discovery from Captain Cook's Endeavour to the Beagle*, (London: Bloomsbury Publishing Plc, 2018)

[26] James Taylor, *The Voyage of the Beagle, Darwin's Extraordinary Adventure Aboard FitzRoy's Famous Survey Ship*, (London: Conway, 2008), p. 168; MacGregor, '91. Ship's Chronometer from HMS *Beagle*', pp. 595-599

Current Interpretations

Recent work within the history of science has challenged these dominant narratives and shown that we should look beyond technological determinism as a solution to the longitude problem and that not one method can be said to have solved the problem overall.[27] Thus, for Miller 'we need to understand the longitude problem, and its solution, in a broader sense' as the longitude 'solution may be universalized in theory but individual determinations of longitude at sea were contingent acts reliant on ... ships, instruments, methods and procedures'.[28] Put this way, we need to understand the chronometer from a different perspective, namely its use within the wider context of its history in maritime navigation.

Studies on the use of chronometry at sea suggested the value of asking questions about their practical use. Nockolds' 1964 paper was pioneering in this respect, although only recently has research addressed the issues she raised. Nockolds queried 'who [which officers] were equipped with timekeepers, cared for them, rated and checked them and [what] use they made of them?'[29] By the beginning of the nineteenth century, those who had experience of chronometry at sea were providing written advice based on their practice. This advice included where to store them, whether or not to move them, how to wind them with care, and how to rate them. It is interesting in this regard to find that the advice from an East India Company Captain differed to that from a Royal Navy Captain, perhaps because of the different purposes of these voyages. Stuart Jennings examined this particular aspect of

[27] Jim Bennett, 'Travels and Trials of Harrison's Timekeeper', in: *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century*, Marie-Noëlle Bourguet, Christian Licoppe, and H. Otto Sibum, eds. (London: Routledge, 2002), pp. 75-95; Richard Dunn and Rebekah Higgitt, *Finding Longitude: How Ships, Clocks and Stars Helped Solve the Longitude Problem*, (Glasgow: Collins, 2014); Richard Dunn and Rebekah Higgitt, eds. *Navigational Enterprises in Europe and its Empires, 1730-1850*, (Basingstoke: Palgrave Macmillan, 2016)

[28] David Phillip Miller, 'Longitude Networks on Land and Sea: The East India Company and Longitude Measurements 'in the Wild', 1770-1840', in: *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds. (Basingstoke and New York: Palgrave Macmillan, 2016), p. 224

[29] G. W. Nockolds, 'Early Timekeepers at Sea', *Antiquarian Horology*, 4:5, (1963), p. 149

experienced officers compiling instructions for the benefit of others.[30] His study of Captain William Fitzwilliam Owen (1774-1857) showed how Owen experimented with chronometers during his deployment on various surveying voyages and how he communicated his recommendations to the Admiralty and to the Board of Longitude. William Owen had been commissioned to survey the east coast of Africa between 1821 and 1827, following which he published a list of latitudes and longitudes prefaced by an essay on the management and use of chronometers.[31] The essay was written by a lieutenant on the voyage, Richard Owen, as a result of what he saw as the lack of regulation and instruction in chronometric methods, and an over reliance on chronometers by officers not taking proper precautions in their use.[32] Jennings explored 'the methods, processes and hierarchies that formed around chronometers on an extended and challenging voyage at a time before any standard practice had been set for surveying voyages'.[33]

Miller has examined chronometric practices within broader networks and he emphasised the importance of other instruments (sextants, octants, artificial horizons) in longitude determinations. Timekeepers were used to assist other methods such as double altitude observations and lunar distances. Miller showed how judgements were made 'on the spot' whilst navigating 'in the wild', depending on 'the condition of the chronometers themselves, the success (or otherwise) with which they had been cared for at sea, the

[30] Stuart Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey', *Antiquarian Horology*, 40, (2019), pp. 200-214

[31] Richard Owen, 'An Essay on the Management and Use of Chronometers', in: *Tables of Latitude, and Longitudes by Chronometer*, William Fitzwilliam Owen, (London; Duckworth and Ireland, 1827), pp. 3-35

[32] The relationship between William Fitzwilliam Owen and Richard Owen is unclear. Dawson states in *Memoirs of Hydrography* that Richard was William Owen's nephew. The entry for Richard Owen in *A Naval Biographical Dictionary* simply lists Richard Owen as the son of a clergyman from county Wexford, Ireland. Neither Burrows or Brown confirm this family link, which makes it more likely that there is none. Llewellyn S. Dawson, *Memoirs of Hydrography*, Part I, (Eastbourne: Henry W. Keay, 1885), p. 126; William R. O'Byrne, *A Naval Biographical Dictionary*, (London: John Murray, 1849), p. 846

[33] Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey', pp. 206-207

constancy of their rates, the reliability of other longitude measures, determinations of local time and, crucially, how much time and effort it was worth investing in potentially superfluous precision'.[34] Miller examined the role of the observatory, particularly Madras and Bombay Observatories, and even considered the ship as one of the instruments used in the method of dead reckoning, thus building on Richard Sorrenson's work which described the 'ship's track [as] a representation of the probing course of the instrument through the sea'.[35] Miller's study also reveals the importance and role of logbooks, textbooks, *The Nautical Almanac*, maps, charts; and the institutions that supported them together with the skills and training navigators required to (successfully) employ these new methods at sea. Miller thus concluded that practices by East India Company captains were a 'situated activity dependent on complex networks'.[36] Instructions formed an important part in the training of East India Company officers. However, in spite of the instructions given regarding lunar observations or chronometric measurements, officers were constrained by what was possible in practice in a particular place and at a particular time: judgements were made 'on the spot'. Miller concluded that '[what] techniques to employ, and how to employ them were, in short, practical choices 'in the wild'.[37] Similarly, Simon Werrett has demonstrated that navigation was a varied practice, where successful navigation was achieved through a 'complex process of adjudicating between methods, instruments, measurements and personnel.[38] Werrett has shown how Russian navigators adopted British navigational

[34] Miller, 'Longitude Networks on Land and Sea', p. 226
[35] Richard Sorrenson, 'The Ship as a Scientific Instrument in the Eighteenth Century', *Osiris*, 11, (1996), p. 229 quoted in Miller, 'Longitude Networks on Land and Sea', p. 227
[36] Miller, 'Longitude Networks on Land and Sea', p. 240
[37] Ibid, p. 241
[38] Simon Werrett, ''Perfectly Correct': Russian Navigators and the Royal Navy', in: *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds. (Basingstoke and New York: Palgrave Macmillan, 2016), p. 126

practices, and equally important, British navigators benefited from Russian 'theoretical and practical resources and patronage'.[39]

What most of these studies have in common is a focus on the shipboard routines established by different users. What we learn from this is that each particular voyage used their chronometers in different ways. They all experienced problems using the instruments and dealt with these issues in their own way. How this was done depended on the perceived reliability of the instruments, the training and instructions received and 'the *selective* pursuit of precision'.[40] Following these lines I examine not only how chronometers were managed at sea, but also why certain practices were implemented. This requires me to examine the particular aims of each voyage, the training and educational history of the officers involved, and their views on the reliability of chronometers. To help in doing so, I draw on research from the histories and historical geographies of science. These approaches allow me to place the chronometer within its wider context and appreciate a more nuanced version of the history of the development of its use at sea, as: 'A widely acknowledged 'spatial turn' across arts and sciences corresponds to post-structuralist agnosticism about both naturalistic and universal explanations and about single-voiced historical narratives, and to the concomitant recognition that position and context are centrally and inescapably implicated in all constructions of knowledge'.[41]

Historical geographies of science

Science has traditionally been considered placeless and universal. In this view, science transcended its settings to achieve an aura of truth and validity. Today, it is more common

[39] Werrett, ''Perfectly Correct': Russian Navigators and the Royal Navy', p. 126
[40] Miller, 'Longitude Networks on Land and Sea', p. 238, original emphasis
[41] Denis Cosgrove, 'Introduction', in: *Mappings*, Denis Cosgrove, ed. (London: Reaktion Books, 1999), quoted in Warf and Arias, 'Introduction: The Reinsertion of Space into the Social Sciences and Humanities', p. 1

to think of science as having both a history and a geography and that its placed nature can help explain the nature of the science in question. Historical geographers of science pay attention to 'science as a cultural formation, embedded in wider networks of social relations and political power, and shaped by the local environments in which its practitioners carry out their tasks'.[42] Rather than viewing science as a disembodied, universal truth awaiting discovery, historians of science now argue that scientific knowledge is shaped, judged and constructed through local values and practices.[43] Empiricist interpretations of science hold the view that theoretical representations of the world can be tested and validated through observation. From this account, the 'world is independent of how we represent it, and our representations may depict the world inaccurately'.[44] Joseph Rouse, however, argued that 'science is a means . . . for constructing and improving representations of the world'.[45] There is no independent world to represent, as the representations themselves are shaped by the observations that are meant to represent them. Science is consequently a situated, local, and social practice: 'science has a geography [and] scientific knowledge bears the marks of particular locations'.[46] The phrase 'finding longitude' neatly encapsulates an empiricist view of science which predominates in the historical literature concerning chronometers and navigation. A historical geographical approach allows the researcher to consider the sites of science's making and application and the social spaces in which it was made and received

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[42] David N. Livingstone, 'Reading the Heavens, Planting the Earth: Cultures of British Science', *History Workshop Journal*, 54, (2002), p. 236

[43] Richard C. Powell, 'Geographies of Science: Histories, Localities, Practices, Futures', *Progress in Human Geography,* 31, (2007) pp. 309-329; Jan Golinski, *Making Natural Knowledge: Constructivism and the History of Science*, (Cambridge: Cambridge University Press, 1998); Crosbie Smith and Jon Agar, 'Introduction: Making Space for Science', in: *Making Space for Science: Territorial Themes in the Shaping of Knowledge*, Crosbie Smith and Jon Agar, eds. (London: Macmillan, 1998) pp. 1-23; David N. Livingstone, *Putting Science in its Place*, (Chicago and London: The University of Chicago Press, 2003)

[44] Joseph Rouse, *Knowledge and Power*, (London: Cornell University Press, 1987), p. 3

[45] Rouse, *Knowledge and Power*, p. 3

[46] Heike Jöns, David N. Livingstone, and Peter Meusburger, 'Introduction: Interdisciplinary Geographies of Science', in: *Geographies of Science, Knowledge and Space, Volume 3*, Peter Meusburger, David N. Livingstone, Heike Jöns, eds. (Dordrecht: Springer, 2010), pp. ix-xvii

and so show how longitude was constructed locally and embedded globally. I thus consider the history of the chronometer within its spatial settings on board a ship sailing in different geographical locations and consider the local practices that occurred within these locations.

Places of knowledge

By acknowledging the situatedness of scientific practice, where science is 'produced', historians of science and historical geographers have illuminated how place shapes and defines scientific activities and how these activities in turn redefine and shape place. For instance, Shapin argued that we need to 'take a close look at the culturally demarcated physical sites from which scientific knowledge has historically emerged' and consider who had access and why, how their behaviour was guided within these spaces, what purposes they may have pursued and how knowledge circulated between specific sites.[47] Knowledge is produced locally, in a specific location, but since science has to travel it need not necessarily remain in any one location. Science travels from place to place, from the context of its discovery to perhaps different contexts of justification, and it is important to investigate the mechanisms by which this happens to understand how local practices of knowledge become accepted global structures.[48] Historians of science have identified that questions of authority, credibility and trust are similarly crucial for the circulation of knowledge and that instrumentation, replication of experiment and questions of precision likewise played a key role.

Place can be considered as a 'location or a site in space where an activity or object is located and which relates to other sites or locations because of interaction, movement and

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[47] Stevin Shapin, *Never Pure: Historical Studies of Science as if It Was Produced by People with Bodies, Situated in Time, Space, Culture, and Society, and Struggling for Credibility and Authority*, (Baltimore: The John Hopkins University Press, 2010), p. 57

[48] Stevin Shapin, 'Placing the View from Nowhere: Historical and Geographical Problems in the Location of Science', *Transactions of the Institute of British Geographers*, 23, (1998), pp. 5-12

diffusion between them'.[49] Museums, libraries, observatories are all specific sites of scientific activity which shape the activities that take place within and beyond their walls. The places where science could be practised (laboratories, observatories, museums, etc.) enhanced the status of the practitioner and the scientific knowledge they generated, but they may also have determined who was allowed to participate. With reference to botany, for the working classes and for women, for example, Anne Secord has shown how by the mid-nineteenth century, many scientific practices operated on a basis of social exclusion.[50] Access to given sites was key: not all participants could take part in the select venues in which some sciences were undertaken.

Place may also be considered a 'series of locales or settings where everyday-life activities take place', shaping the behaviour of its inhabitants and structuring their social interaction.[51] The ship is a good example of this and has been seen as a heterotopic 'floating laboratory,' or an 'itinerant observatory,' in direct contact with the field site in which scientific activities were conducted.[52] The spatial dimensions of the ship determined varying degrees of social and epistemic visibility, controlled access to objects and instruments of research, controlled the movement between workplaces and the interactions between people. Only gentlemen officers could walk the quarterdeck, engage in scientific pursuits at sea, access instruments, consult textbooks and take part in shipboard training, which often required admission to the captain's cabin.

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[49] John A. Agnew, 'Space and Place', in: *The SAGE Handbook of Geographical Knowledge*, John A. Agnew and David N. Livingstone, eds. (London: SAGE Publications Ltd, 2011), p. 326
[50] Anne Secord, 'Science in the Pub: Artisan Botanists in Early Nineteenth-Century Lancashire', *History of Science*, 32; (1994), pp. 269-315
[51] Agnew, 'Space and Place', p. 326
[52] Simon Naylor, 'Weather Instruments all at Sea: Meteorology and the Royal Navy in the Nineteenth Century', *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), p. 77; Michel Foucault and Jay Miskowiec, 'Of Other Spaces', *Diacritics*, 16, (1986), pp. 22-27

Place can also be understood as a particular and singular entity; 'a unique community, landscape, and moral order'.[53] Places are more than 'isolated entities'; they are located in series of extensive economic, political, and cultural networks with varying geographical scope'. The venues for science may, thus, be 'a range of sites where scientific knowledge might be constructed at a distance'; for example, societies, lectures tours, exhibitions, and publications.[54] In the late eighteenth and early-nineteenth centuries, scientific practitioners operated within and across political and cultural networks. Levere described science as more than its context: 'it has its inner dynamics, directed through its institutions and applied through instruments and concepts to an uncompromising natural world'.[55] As Levere has shown, science played a key role in Arctic exploration and the majority of officers who commanded these British voyages to the region were elected Fellows of the Royal Society. John Barrow (1764-1848) was a fervent promotor of Arctic exploration: it held 'the key to national honour, individual fame and navigational success in high latitudes'.[56] In his study of the social organisation of science in the Arctic, Bravo argued that following the Napoleonic Wars (after 1815) the Royal Navy collaborated with the Royal Society in pursuing scientific activities within Regency Britain. Naval officers and Royal Society observers worked together, often using the same scientific instruments, although with different purposes in mind.[57] Bravo described this as a complex arrangement where 'two different fields of enquiry' were pursued.[58] Despite having different aims, both groups used the same instruments to conduct similar measurements. Different experimental practices were 'central to achieving the goals

[53] Agnew, 'Space and Place', p. 327
[54] Simon Naylor, 'The Field, the Museum and the Lecture Hall: The Spaces of Natural History in Victorian Cornwall', *Transactions of the Institute of British Geographers*, 27, (2002), p. 495
[55] Levere, *Science and the Canadian Arctic*, p. 2
[56] I. A. MacLaren, 'John Barrow's Darling Project (1816-1846)', in: *Arctic Exploration in the Nineteenth Century*, Frédéric Regard, ed. (London: Pickering & Chatto, 2013), p. 20
[57] Michael Trevor Bravo, *Science and Discovery in the Admiralty Voyages to the Arctic Regions in Search of a North-West Passage (1818-25)*, Unpublished PhD, University of Cambridge, (1992), p. iii
[58] Bravo, *Science and Discovery in the Admiralty Voyages to the Arctic Regions*, p. 113

of the expeditions, both in terms of geographical discovery and regulatory science'.[59] The cooperation between Royal Society observers and Naval officers led to relationships in which naval officers were trained to become observers. While this is true, it is also the case that navigational science is generally left aside in these accounts, with the focus more often upon astronomy, terrestrial magnetism, hydrography, geography, natural history, geology and zoology.[60]

Place should, therefore, be a central concern in an account of the history of chronometric practices. Geography is 'a necessary prerequisite for science to even take place'.[61] Local accomplishments are important, because they, and not universal constants, produce 'evidential warrant and experimental procedure'.[62] The world itself is 'spatialized by science', as it 'creates spaces and places for its own activities', thereby making geographies of science.[63] The specific location in which science is made is more than just a geographical coordinate; it is an 'active ingredient in social and cultural life'.[64] All activities, conceptions, constructions and judgements relating to epistemology are informed by the social and the local.[65] However, a focus on place is only part of the construction of knowledge as the 'wide distribution of scientific knowledge flows from the success of certain cultures in creating and spreading standardized contexts for making and applying that knowledge'.[66]

[59] Ibid, p. 172
[60] Levere, *Science and the Canadian Arctic*, pp. 142-189
[61] Naylor, 'Introduction: Historical Geographies of Science', p. 2
[62] Diarmid A. Finnegan, 'The spatial turn: Geographical approaches in the History of Science', *Journal of the History of Biology*, 41, (2008), pp. 369-388
[63] Simon Naylor, 'Introduction: Historical Geographies of Science – Places, Contexts, Cartographies', *The British Journal for the History of Science*, 38, (2005), pp. 1-12
[64] Finnegan, 'The spatial turn', p. 371
[65] Adi Ophir and Steven Shapin, 'The Place of Knowledge; A methodological survey', *Science in Context*, 4, (1991), pp. 3-21
[66] Stevin Shapin, 'Here and Everywhere: Sociology of Scientific Knowledge', *Annual Review of Sociology*, 21, (1995), p. 308

Authority, credibility and trust in science

A central question in the spatial history or historical geography of science is 'how and why does knowledge circulate?'.[67] To be considered universal truths, scientific or knowledge claims must somehow transcend their locality and their relation to place in order to achieve a 'placeless' validity. A field scientist, for example, must 'create a place, situate inquiry there, fashion it into a truth-spot from which abstract, universal, and transcendental claims might soar, give beliefs a provenance'.[68] This means that for the field scientist, 'being there' lends credibility to the knowledge produced in that particular location. In a laboratory, this is not the case. Here, the social and local aspects where the claim is produced can be seen to taint, and thus discredit, the claim as a universal truth. Laboratory science requires instrumentation, standardisation, replication, and above all, objectivity, to become '*a place denied*'.[69] The practices should be replicated anywhere, and yield the same results, what Thomas Gieryn calls a 'paradox of place and truth'. The paradox is that it is the place that allows the claim to transcend; it being achieved through 'the geographic, architectural and rhetorical construction of a "truth-spot"'.[70] The place where facts are produced lays down the rules by which the claim is validated. What Gieryn is urging us to do is to understand how knowledge claims are produced in a particular location, and then to investigate how mechanisms were employed for those claims to be accepted on a global scale.

Shapin argued that a fundamental requisite in knowledge circulation is that of trust: in the scientist, in her or his words, and in the claims to evidence that are at any time advanced or written in support of an argument. This means we must look at themes relating to authority and credibility – at how science is practised and against what forms of judgement

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[67] James A. Secord, 'Knowledge in Transit', *Isis*, 95, (2004), p. 655
[68] Gieryn, 'Three Truth-Spots', p. 117
[69] Ibid, p. 130
[70] Ibid, p. 113

as to its accuracy or precision – to understand how knowledge is generated in science.[71] Science at sea was a collaboration between the state, particular institutions such as the Admiralty and social groups operating at sea. Nineteenth-century scientific practices at sea operated through collaboration and with the support of scientific societies, but it was the Royal Navy that facilitated these opportunities in practice and particular ships' crews that instantiated them.[72] One element of understanding the making of science at sea and trust in sea-borne science is to examine the structure, influence and aims of the communities and individuals involved and how they operated.

'Disciplinarity' is a constructivist analysis that examines how scientific disciplines are embedded in larger networks of power. In these terms, 'discipline formation requires the consolidation of a community that shares a particular model of practice, which in turn implies modes of regulating behavior'.[73] Golinski stressed that this 'discipline' simultaneously operated 'as both a form of instruction to which one submits and to a means of controlling behaviour'.[74] Knowledge production in this view is mutually constitutive: knowledge is constructed through the disciplining of the individual by training and instruction in a particular method or practice, and, at the same time, the individual is constrained and judged by their ability to produce the required results according to the norms of the emergent discipline. The institution in which an individual works, or to which an individual is affiliated, characterises the nature of the scientific pursuit, or the 'particularities of practice that characterise it'.[75] At the same time, the institution is itself shaped and consolidated by the pursuits of the individuals operating within its constraints. 'Institutions are social

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[71] Shapin, 'Placing the View from Nowhere', pp. 5-12
[72] Randolph Cock, *Sir Francis Beaufort and the Co-ordination of British Scientific Activity, 1829-55*, Unpublished PhD, University of Cambridge, (2002), p. 5-22
[73] Golinski, *Making Natural Knowledge*, p. 69
[74] Ibid, p. 69
[75] Ibid, p. 55

constructions in that their definitions, relationships, values and goals are negotiated by ordinary people in ordinary settings . . . The institution is available for multiple and not always consistent descriptions and explanations'.[76]

Miller has shown how this applied to the navigational practices of the East India Company. Navigational practices on board East India Company ships were a result of their 'elaborate system of qualification for officers [which] ensured a fairly rigorous training'. This training 'was provided through a complex network of teachers and examiners, and through training aboard ship, rather than a single institution'.[77] It is clear from Miller's research that although the institution is important in shaping the general pursuit of navigation in the East India Company, the specific and particular place, or even range of places, where officers were trained was equally, if not more, important. The training of officers to use scientific instruments at sea is, thus, an important aspect in the development of navigational practices and the credibility of the individuals involved; however, when it came to actual shipboard practice, 'the navigator employed techniques that were practicable and that sufficed rather than those that were ideal from a theoretical, hydrographic or administrative viewpoint'.[78] Place informs not just '*where* things happen' but also '*how* and *why* they happen'.[79] Thus, to understand these practices we need to understand the practitioners, and the context in which they operated as this determined how they used chronometers to negotiate authority and expertise.

The early nineteenth century was in many ways a transformational period in terms of the emergence of scientific practice at sea. Joseph Banks' presidency of the Royal Society

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[76] Thomas Gieryn, 'Distancing Science from Religion in Seventeenth-Century England', *Isis*, 79, (1988), pp. 588-589, quoted in Golinski, *Making Natural Knowledge*, p. 55
[77] Miller, 'Longitude Networks on Land and Sea', p. 232
[78] Ibid, p. 241
[79] Barney Warf and Santa Arias, 'Introduction: The Reinsertion of Space into the Social Sciences and Humanities', in: *The Spatial Turn, Interdisciplinary Perspectives*, Barney Warf and Santa Arias, eds. (Abingdon: Routledge, 2009), p. 1, original emphasis

(1778-1820) ‘marked a transition from a State which could still use the services of an outside gentleman expert to one which increasingly relied on professional civil servants’.[80] Eóin Phillips has demonstrated the importance of ‘trust, visibility and discipline’ for ships’ captains.[81] Astronomers accompanying voyages of exploration were trusted by the Board of Longitude to perform astronomical duties and to train others to do so to. Others were not. Scientific knowledge became embodied in ‘skilled people, in scientific instruments, or in the transactions between people and knowledge-making devices’.[82] To implement the new technologies and methods of finding longitude more broadly across the Royal Navy required a transformation in how naval officers were trained so that the knowledge they produced and documented could be established and standardised so that both the personnel and the knowledge claims could be trusted.[83]

The end of the Napoleonic Wars saw an increasing role for the Royal Navy in British science. John Barrow, Second Secretary to the Admiralty, pursued ‘the advancement of geography, navigation and commerce’ after 1815.[84] The role of state institutions, such as the Admiralty, the Board of Longitude, and the Hydrographic Office, was to identify and support ‘select individuals and relatively informal groups as trusted advisors’.[85] Naval officers increasingly pursued scientific careers in surveying and exploration. Within the Royal Navy of the 1820s, they operated within the strict hierarchies of the Admiralty, although the scientific and navigational aims they pursued were set by bodies such as the Royal Society, the Board

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[80] John Gascoigne, *Science in the Service of Empire: Joseph Banks, the British State and the Uses of Science in the Age of Revolution*, (Cambridge: Cambridge University Press, 1998), p. 199
[81] Eóin Phillips, ‘Instrumenting Order: Longitude, Seamen and Astronomers’, in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. F. Withers, eds. (Abingdon: Routledge, 2016), p. 39
[82] Shapin, ‘Here and Everywhere’, p. 306
[83] Eóin Edward Phillips, *Making Time Fit: Astronomers, Artisans and the State, 1770-1820*, Unpublished PhD, University of Cambridge, (2014), pp. 162-163
[84] Barrow quoted in Miller, ‘The Revival of the Physical Sciences in Britain, 1815-1840’, p. 113
[85] Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 2

of Longitude, and the Pendulum Committee. For Waring, the Board of Longitude was 'a location of interaction for authority and expertise'.[86] During this period, and certainly after the dissolution of the Board of Longitude in 1828, the Hydrographic Office played an increasingly large role in establishing these pursuits. This is not to deny that individual pursuits also shaped navigational science. William Edward Parry (1790-1855) attempted to improve surveying although it was Francis Beaufort who became a pivotal figure in co-ordinating scientific activity within the Royal Navy.[87] Basil Hall was instrumental in bringing about the first naval expedition solely devoted to the pursuit of the physical sciences under Captain Foster in 1828. Henry Kater (1777-1835), like the above a Fellow of the Royal Society, was instrumental in establishing guides and training for individuals.[88] Thomas Young (1773-1829), Secretary to the Board of Longitude and Superintendent of the *Nautical Almanac*, and Davies Gilbert (1767-1839), President of the Royal Society (1827-1830), likewise 'believed almost exclusively in the model of scientific individualism and this shaped their management of state-science interaction'.[89]

Waring has cautioned scholars not to consider these and other individuals a 'well-institutionalised or consensual scientific community in Britain'.[90] Miller has linked the pursuit of the physical sciences in Britain between 1815 and 1840 to the 'skills and ambitions of three groups – mathematical practitioners, the Cambridge network, and scientific servicemen'.[91]

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[86] Sophie Waring, 'The Board of Longitude and the Funding of Scientific Work: Negotiating Authority and Expertise in the Early Nineteenth Century', *Journal for Maritime Research*, 16, (2014), p. 55

[87] Cock, *Sir Francis Beaufort and the Co-ordination of British Scientific Activity, 1829-55*, p. 15; Adrian Webb, 'More than Just Charts: Hydrographic Expertise Within the Admiralty', *Journal for Maritime Research*, 16, (2014), pp. 43-54

[88] David Phillip Miller, *The Royal Society of London 1800-1835: A Study in the Cultural Politics of Scientific Organisation*, Unpublished PhD, University of Cambridge, (1981), pp. 180-188; Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, pp. 119-122; A. J. Webb, 'The Hydrographer, Science and International Relations: Captain Parry's Contribution to the Cruise of HMS *Chanticleer*, 1828-9, *The Mariner's Mirror*, 96, (2010), pp. 62-71

[89] Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 3

[90] Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 1

[91] Miller, 'The Revival of the Physical Sciences in Britain', p. 107

The mathematical practitioners were linked to the Royal Military Academy, and the Royal Military College where they taught mathematics, astronomy and surveying. Banks' influence at the Royal Society meant that natural philosophy was favoured over the physical sciences, a fact which led to a push for reform by the mathematical practitioners. The Cambridge Network 'promoted institutional reforms and innovations at Cambridge University, in the Royal, Astronomical, and Geological societies and in the British Association for the Advancement of Science'.[92] The scientific servicemen were members of the armed services employed in surveys and voyages of exploration. In the early-nineteenth century, this was 'a core of naval officers . . . associated with the Admiralty Hydrographic Office [who] took an increasing pride in their scientific acquirements and sought recognition in the scientific community of the metropolis'.[93]

The context in which technologies were implemented had a direct effect on how they were used and on their subsequent development.[94] 'Science was not one thing', Shapin argued; but 'a variety of practices whose conceptual identities were the outcomes of local patterns of training and socialization'.[95] Similarly, for Waring, 'while the actions of the military-fiscal state may have helped to construct and consolidate a scientific community around commissioned activities and tasks, this process of construction used highly informal patterns of sociability, networking, and patronage'.[96] Simon Naylor examined 'science through its spaces of activity and its networks of geographies'. This methodology revealed the invisible practitioners who helped establish methods for a tradition of science.[97] Although Naylor's research explored less known naturalists, chemists and astronomers as invisible

[92] Miller, 'The Revival of the Physical Sciences in Britain', p. 110
[93] Ibid, p. 112
[94] Dunn and Higgitt, *Navigational Enterprises in Europe and its Empires, 1730-1850*, pp. 1-10
[95] Shapin, 'Placing the View from Nowhere', p. 6
[96] Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 2
[97] Naylor, 'The Field, the Museum and the Lecture Hall', p. 510

practitioners, rather than the 'well-known researchers' in a 'traditional hagiographic approach to the history of science', I wish to draw from this approach to consider the actions of the 'invisible practitioners' of chronometry, i.e. the naval servicemen who, 'played a very significant, if largely unsung, role in British science' and remain largely invisible within the history of the chronometer.[98]

Circulation of knowledge

'The spatial turn stressed that ideas and theories should be understood as always being embodied in material objects, from human bodies to books, papers, instruments, and other "immutable mobiles" as sociologist Bruno Latour called them'.[99] Thus, science is 'an embodied practice involving primarily the manipulation of *things*'.[100] These things include instruments, humans, textbooks, paper, graphs, maps, and even ships: together, 'a concrete collective practice of producing, assessing, and circulating material objects designated as carriers of natural knowledge'.[101] Knowledge is thus an outcome of stabilised processes and the manipulation of 'things' in a network: 'knowledge production displays a complex geography as it is both situated within particular locations and linked to other places through mostly circulatory movements'.[102] By passing through these other places, or centres, geographical knowledge of other places emerges. The processes that take place at such a centre of calculation include 'the mobilisation of resources, the stabilisation of new knowledge claims and the extension of knowledge networks of the validation, dissemination

[98] Quotes respectively in Naylor, 'The Field, the Museum and the Lecture Hall', p. 510 and Miller, 'The Revival of the Physical Sciences in Britain', p. 112
[99] Simon Werrett, 'Matter and Facts: Material Culture and the History of Science', in: *Material Evidence: Learning from Archaeological Practice*, Alison Wylie and Robert Chapman, eds. (New York: Routledge, 2014), p. 348
[100] Werrett, 'Matter and Facts: Material Culture and the History of Science', p. 348, original emphasis
[101] Ibid, p. 348
[102] Heike Jöns, 'Centre of Calculation', in: *The SAGE Handbook of Geographical Knowledge*, (London: SAGE Publications Ltd., 2011), p. 159

and preservation of knowledge and its products'.[103] The resources used to produce knowledge are varied; these can be books, documents, instruments, methods, observations, data, maps, charts and drawings. Latour considers three aspects that these resources require to 'act at a distance'; that the resources are mobile, that they are stable, and that they can be combined to allow for accumulation and aggregation.[104] Instruments, observations, methods, data, documents, books, maps and drawings, become 'immutable and combinable mobiles'.[105] Through this process, distant places are made familiar, and potentially, controllable.[106]

Work within the sociology of scientific knowledge (SSK) has examined the mundaneness of science, 'displaying the contingency, informality, and situatedness of scientific knowledge-making'.[107] Science in this light, is not produced by humans with exceptional abilities, but by and through 'ordinary human cognitive capacities and ordinary forms of social interaction'.[108] By studying scientists in their daily activities, Latour examined how scientists used different rhetorical and epistemological devices to convince others of the validity of their scientific activity and to secure it as fact.[109] This 'rhetorical turn' examines 'the textual and informal means by which scientists labor [sic] to persuade others, to extend experience from private to public domains, to assure others of their disinterestedness, to assert the significance of their claims, to argue that their body of knowledge is indeed "scientific"'.[110] For those working in the field in the nineteenth century, 'credibility was a matter of demonstrating in appropriate ways the epistemological and moral warrant that, if

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103 Jöns, 'Centre of Calculation', p. 159
104 Bruno Latour, *Science in Action*, (Cambridge Massachusetts: Harvard University Press, 1987), p. 223
105 Latour, *Science in Action*, p. 227
106 Jöns, 'Centre of Calculation', p. 159
107 Stevin Shapin, 'Here and Everywhere: Sociology of Scientific Knowledge', *Annual Review of Sociology*, 21, (1995), p. 305
108 Shapin, 'Here and Everywhere', p. 305
109 Latour, *Science in Action*, pp. 21-62
110 Shapin, 'Here and Everywhere', p. 305

properly wrought, would facilitate the circulation of their testimony and secure their reputational status as tellers of truth'.[111]

In his Actor-Network Theory (ANT), Bruno Latour proposes that 'instead of starting from universal laws – social or natural – and to take local contingencies as so many queer particularities that should be either eliminated or protected', ANT encourages us to start locally and trace these 'irreducible, incommensurable, unconnected localities' and examine how they end up forming 'commensurable connections'.[112] ANT describes activities relating to the building of knowledge and has proven controversial. Critics of ANT state that it is 'culturally flat', as is does not recognise that technoscience operates within the context of culture and practice and that trust is a central feature in science. ANT attributes not just equal agency to humans and non-humans, but also equal intentionality. Finally, ANT often focuses on heroics or failures, failing to recognise the mundane and the structures that marginalise others.[113] According to Edwin Sayes, ANT can be seen as a tool to 'better attend to the minute displacements, translations, practices, riots, processes, protests, arguments, expeditions, struggles and swap-meets – no matter what the actors involved may look like', realising that even without intention, a non-human can and does have influence within scientific networks.[114] This approach encourages a focus on what it was that connected determinations of longitudes which were conducted by different people, using different instruments, following different instructions, all at different locations. I have, therefore sought out additional materials that were used and produced within navigational and scientific

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111 Innes M. Keighren, Charles W. J. Withers, Bill Bell, 'Writing the Truth, Claims to Credibility in Exploration and Narrative', in: *Travels into Print: Exploration, Writing, and Publishing with John Murray, 1773-1859*, Innes M. Keighren, Charles W. J. Withers, Bill Bell, eds. (London: University of Chicago Press, 2015), p. 99

112 Bruno Latour, 'On Actor-Network Theory, a Few Clarifications', *Soziale Welt*, 47, (1996), p. 370

113 Sergio Sismondo, *An Introduction to Science and Technology Studies*, (Chichester: Blackwell Publishing Ltd, 2010), pp. 81-92

114 Edwin Sayes, 'Actor-Network Theory and Methodology: Just What Does It Mean to Say That Humans Have Agency?', *Social Studies of Science*, 44, (2014), p.148

networks, specifically ones that have been overlooked before now, and examine how they interacted within these networks in bringing together these disparate elements.

From the late eighteenth century, precision instruments were increasingly relied upon to bridge distances between the sites of science's making, perhaps commonly between the periphery and the centre. 'Precision', Bourguet wrote, 'is importantly involved in the commensurability of work at separated sites'.[115] Authority became associated with, even embodied in figures, tables and graphs.[116] The manpower of the Royal Navy allowed this data collection to be pursued on a large scale. Naval surveying, Randolph Cock pointed out, was 'an organised network of observers spreading precise, disciplined measurement and accurate maps across the globe'.[117] Chronometric methods were developed within these practices, and as a result, were shaped by these developments as, in turn, they helped shape the practices with which they were associated. MacDonald and Withers conclude that 'by the late eighteenth century, questions of method in an increasingly disciplined natural philosophy – what from the 1830s would become Science and the sciences – were predicated not only upon the regulation of observations and of inscription, but also upon the epistemic authority of numbers and of measurement'.[118] The accumulated data formed both an input and an output. The data was 'systemized, classified, transformed, tied together and re-represented in order to build a strong web of associations that makes up a new knowledge claim'.[119]

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[115] Marie-Noëlle Bourguet, Christian Licoppe and H. Otto Sibum, 'Introduction', in: *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century*, Marie-Noëlle Bourguet, Christian Licoppe and H. Otto Sibum, eds. (London: Routledge, 2002), p. 8
[116] Bourguet, 'Introduction', p. 8
[117] Cock, *Sir Francis Beaufort and the Co-ordination of British Scientific Activity, 1829-55*, p. 10
[118] Fraser MacDonald and Charles W. J. Withers, 'Introduction: Geography, Technology and Instruments of Exploration', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), p. 2
[119] Jöns, 'Centre of Calculation', p. 160

In the context of chronometric practices at sea, exploring these avenues will provide a broader understanding of how data was produced at sea (by instruments that were considered inherently unreliable) and how it was manipulated and reconstructed to inform and discipline subsequent practices.

Instruments, replication and precision

Contemporary ethnographic approaches to science have studied the ways in which scientists perform within the laboratory and how the results they produce are exported to other locations through standardised instrumental practices.[120] These approaches have been applied to historical developments of technology and science in order to explore the past from different perspectives. Such a social constructivist approach does not separate science from technology but instead focuses on how technology helped constitute science. Such an approach challenges the view of technology as subordinate to science, and has, as a result, produced the 'technological turn' which places both science and technology on equal footing and does so through a focus on instrumentation and 'instrument epistemology'.[121] Davis Baird argued that we need to acknowledge that instruments themselves are 'epistemologically important'.[122] Baird considered instruments 'on par with theory', and, as such, they 'bear knowledge. Instruments are not in the intellectual basement; they occupy the same floor as our greatest theoretical contributions to understanding the world'.[123] Rather, scientific instruments are 'material products of science and technology that constitute our knowledge'.[124] Under Baird's terms, when thinking about 'thing knowledge', a

[120] Golinski, *Making Natural Knowledge*, pp. 79-102; Powell, 'Geographies of science', pp. 316-318
[121] MacDonald and Withers, 'Introduction: Geography, Technology and Instruments of Exploration', p. 6
[122] Davis Baird, *Thing Knowledge: A Philosophy of Scientific Instruments*, (London: University of California Press Ltd, 2004), pp. 1-4
[123] Baird, *Thing Knowledge*, p. xvii
[124] Ibid, p. 1

chronometer would fall into the category of 'measuring instruments'. This is because of what they *do:* 'measuring presupposes representation, for measuring something locates it in an ordered space of possible measurement outcomes. A representation – or model – of this ordered space has to be built into a measuring instrument'.[125] The knowledge produced by a chronometer was 'encapsulated knowledge': the instrumental measurement was a result of 'effective action and accurate representation'.[126]

The replication of experimental practices using these instruments to produce the desired results is equally important in the construction of navigational knowledge. The credibility of one voyage could be confirmed, adjusted or even refuted by another voyage replicating the same observations or measurements. Collins argues that 'confirmatory power . . . seems to increase as the differences between a confirming experiment and the initial experiment increases'.[127] Two different experiments, say an astronomical observation and a mechanical measurement, producing the same results, would therefore enhance the experiments' confirmatory power, especially if they were performed by persons deemed credible to make the experiments. This is again a matter of trust. Replicating an experiment requires more than a device and a manual. Only certain individuals had the access to the training, skill and tacit knowledge that were prerequisites to performing these experiments. Human skill, not laws of nature, produce 'experimental regularity'.[128] Accuracy is in that sense an 'administrative achievement'.[129] Wynne suggested that we explore 'what kinds of rule-

[125] Ibid, p. 12
[126] Ibid, pp. 12-13
[127] Henry Collins, *Changing Order, Replication and Induction in Scientific Practice*, (London: University of Chicago Press Ltd, 1992), p. 34
[128] Theodore M. Porter, *Trust in Numbers, The Pursuit of Objectivity in Science and Public Life*, (Chichester: Princeton University Press, 1995), p. 13
[129] Porter, *Trust in Numbers*, p. 14

following behaviour are involved in technologies, and how reproducible, generalizable, or controllable are they?'[130]

Bourguet pointed out that 'to enforce modes of commensurability between distant places, objects or phenomena, instruments have first to be calibrated and made comparable under a common standard'.[131] This can be achieved through disciplinary practice. In the first instance this requires disciplining the makers to produce instruments according to standardised designs and methods. John Harrison's marine timekeepers are a good example of this. For his timekeepers to work at sea, they had to 'become commodities that could travel everywhere and be read by anybody'. The problem with Harrison's timekeeper was that it 'lacked a method which would allow it to become a replicable commodity' and it was therefore 'bound to the unique craftsmanship of its maker'. For Bourguet, only when the 'watch mechanism could be explicated and produced according to a general principle [could Harrison] be construed as a discoverer of an accurate and certain method'.[132] The technological history of the chronometer testifies as to how challenging that proved to be. After chronometer makers Arnold and Earnshaw had achieved this, astronomers were required to teach the necessary skills to seamen, because they were trusted to keep accurate records 'based on their mathematical and astronomical skill'.[133] Precision, and the moral values associated with it, is a 'cultural achievement, one rooted in the pursuit of unity'.[134]

[130] Brian Wynne, 'Unruly Technology: Practical Rules, Impractical Discourses and Public Understanding', *Social Studies of Science,* 18, (1988), p. 149
[131] Bourguet, 'Introduction', p. 9
[132] Ibid, p. 10
[133] Phillips, 'Instrumenting Order', pp. 53-54
[134] M. Norton Wise, 'Precision: Agent of Unity and Product of Agreement', in: *The Values of Precision*, M. Norton Wise, ed. (Chichester: Princeton University Press, 1995), p. 359

Exploration and surveying voyages not only applied new technologies but sought to test the instruments themselves, in varying geographies and circumstances.[135] Several studies have shown how experimental practices with instruments involved a continuous circulation of the instrument's status: from object of investigation, to a tool for making measurements, almost always falling back to being an object of investigation (servicing and repair, rating, calibration for specific climates) before reverting to a tool again.[136] Adequate functioning of an instrument relied on 'outcomes that are the same or can be understood to be the same given an analysis of error'.[137] A further problem with replication is the ability to determine if the experiment has been successful since the success of an experiment can only be determined if the experiment yields the correct results. The difficulty lies in cases where the result is unknown: when the existing scientific knowledge does not help to decide whether an experimental result is reliable, the attempt to prove scientific claims lead into an infinite regress: whether the experiment is implemented in a competent way or not can only be determined by the accuracy of the results. Yet the decision about the results depends on the experiment and whether it is competently conducted.[138] Collins termed this experimenters' regress; Meyer and Schulz-Schaeffer described it as a regress of truth.[139] From a sociologist's point of view, the correct result, or overall truth, is not the point: the point is what is commonly accepted as the truth in a particular field. The 'closure' of a

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135 Richard Dunn, 'North by Northwest? Experimental Instruments and Instruments of Experiment', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016) pp. 57-75

136 Dunn, 'North by Northwest?'; Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey'; Mathew Goodman, 'Proving Instruments Credible in the Early Nineteenth Century: The British Magnetic Survey and Site-Specific Experimentation', *Notes and Records of the Royal Society*, 70, (2016), pp. 251-268; Sarah Louise Millar 'Science at Sea: Soundings and Instrumental Knowledge in British Polar Expedition Narratives, *c.*1818-1848', *Journal of Historical Geography*, 42, (2013), pp.77-87

137 Baird, *Thing Knowledge*, p. 12

138 Uli Meyer and Ingo Schulz-Schaeffer, 'Three forms of Interpretative Flexibility', *STI Studies*, Special Issue 1, (2006), p. 28

139 Meyer, Ingo Schulz-Schaeffer, 'Three forms of Interpretative Flexibility', p. 28

controversy is a social negotiation.[140] In this way, 'precision is the result, rather than the cause, of consensus among scientific practitioners'.[141]

Precision and accurate recordkeeping were embedded in early nineteenth-century science: quantification became increasingly synonymous with authority. This authority could be achieved through various procedures. Theodore Porter termed one of these 'disciplinary objectivity': this required consensus, evidence of expertise and appropriate conduct.[142] 'Mechanical objectivity', in contrast, was achieved by individuals following standardised rules and procedures to make decisions. Practitioners would follow rules leading to 'rigorous method, enforced by disciplinary peers, cancelling the biases of the knower and leading ineluctably to valid conclusions.'[143] The values produced are therefore not objective knowledge, but a direct consequence of those imposing the rules and procedures that are followed. Through this imposition, they remake the world according to these values. Standardisation was critical as users became disciplined by these numbers; to achieve uniformity, they had to act uniformly. This reinforced administrative power: 'if expertise means the authority to exercise discretion, grounded on a presumption of superior judgement informed by special knowledge, then trust in numbers reflects suspicion and not merely faith in experts'.[144] Initially, numbers will require interpretations and decisions regarding their accuracy will need to be made. Increased quantification will eventually lead to official stabilised values that appear natural or evident. Quantitative objectivity requires us to understand 'the intellectual formation of experts' and 'the social basis of authority'.[145]

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[140] Ibid, p. 28
[141] Simon Schaffer, 'Accurate Measurement is an English Science', in: *The Values of Precision*, M. Norton Wise, ed. (Chichester: Princeton University Press, 1995), p. 135
[142] Porter, *Trust in Numbers*, pp. 3-8
[143] Ibid, p. 4
[144] Theodore M. Porter, 'Books in Summary: Trust in Numbers: The Pursuit of Objectivity in Science and Public Life', *History and Theory*, 35, (1996), p. 149
[145] Porter, *Trust in Numbers*, p. 6

What is hidden from view here is 'the values of the people who have pursued precision, which people, and to what ends'.[146]

With these ideas in mind, I want to argue that it is important to think of a historical geography of chronometry, in which we consider where it took place, how it was put to work and under what social and material operating conditions.

A historical geography of the chronometer

A historical geography of the chronometer that builds on the perspectives and approaches outlined above means examining the 'specific circumstances of scientific practices and the ways in which the travel of scientists, resources, and ideas shape the production and circulation of scientific knowledge'.[147] As noted, a central theme in the history of science is that of the circulation of scientific knowledge. The thematic approach of the thesis reflects this. Although the focus of the thesis is to examine actual ship-board practices, this approach allows me to consider these practices in relation to the broader context of science, naval training and navigational instructions in the early nineteenth century. An argument based on technological determinism would propose that the introduction of chronometers 'forced social adaptions' through their use at sea.[148] But by applying a Social Constructivist of Technology (SCOT) analysis, I hope to illuminate the role of the users in the history of chronometry since 'the success of an artifact depends upon the strength and size of the group that takes it up and promotes it'.[149] The history of the chronometer will therefore become a more global one, as we visit distant places where they were put to use, and a more timeless

[146] M. Norton Wise, 'Introduction', in: *The Values of Precision*, M. Norton Wise, ed. (Chichester: Princeton University Press, 1995), p. 4
[147] Jöns, Livingstone, Meusburger, 'Introduction: Interdisciplinary Geographies of Science', p. ix
[148] Sismondo, *An Introduction to Science and Technology Studies*, p. 96
[149] Sismondo, *An Introduction to Science and Technology Studies*, p. 99

one, as we consider how old and new technologies existed and were used alongside one another.[150]

What follows is thus a historiography and a historical geography of the chronometer that examines the 'chronometer in action'. Drawing on the work from Bruno Latour, I shall follow the chronometer from Greenwich, to sea, and back again.[151] By taking this approach I wish to draw attention to more than just the instruments and those using them, and to take into account the 'background assumptions, methodologies, techniques, social rules and institutions, routines, experiments, measurements, and the appropriate instruments as well as scientific texts'.[152]

[150] David Edgerton, *The Shock of the Old, Technology and Global History Since 1900*, (London: Profile Books, Ltd, 2008)
[151] Bruno Latour, *Science in Action*, pp. 1-17
[152] Wolfgang Detel, 'Social Constructivism', in: *International Encyclopaedia of the Behavioural Sciences*, James D. Wight, ed. (2015), p. 230

3

Testing and Trialling: The Royal Observatory and the Authority of Astronomers

> The first object of this establishment would be, to procure a certain number of good chronometers; which would be done by the officer in charge, in conjunction with the Board of Longitude. These chronometers would be instantly exposed to severe & deliberate scrutiny, & would not be sent on board ship till their merits were fully ascertained. All chronometers at present belonging to the Admiralty would be sent to the depot, & whenever a ship came to anchor her chronometer should be sent there also; and officers ought to be allowed the advantage of sending any which belonged to themselves, if they chose to do so.[1]

Introduction

Basil Hall's concern regarding the regulation of chronometers was not uncommon in this period; the Admiralty did not do enough to support chronometer use at sea. By the end of the eighteenth century, the efforts of Arnold and Earnshaw in particular, with financial support from the Board of Longitude, had led to an increase in the number of chronometers produced. Specifically, Arnold's technical improvements combined with Earnshaw's large-scale production method allowed larger production numbers that could be sold at a lower cost. By the first two decades of the nineteenth century, however, production numbers were still low and demand continued to outweigh supply. Despite what some contemporary writers perceived as a lack of support from the Admiralty, financial support from the Board of Longitude and the Admiralty had been crucial to chronometer makers in these early years.[2] By 1842, this had changed: 'it [the chronometer] is no longer dependent upon government patronage: the universal conviction of its importance and utility has so increased the demand

[1] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956

[2] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956; *Naval Chronicle*, Vol. 27, (1812), pp. 121-122; Don Manual Alvarez Espriella, *Letters from England*, 1808, quoted in W. E. May, 'How the Chronometer Went to Sea', *Antiquarian Horology*, 9, (1976), p. 644

as to secure vigorous competition on the part of the artist, and render it an article of commerce'.[3] This was not a natural progression as patronage remained a central issue for the success of chronometers during the 1820s. This lack of support did not relate only to chronometers, as the Admiralty did not do enough to implement standards and procedures that would improve navigation overall. In 1808, commanding officers of vessels, or those officers in charge of navigating the ship, were expected to buy their own instruments including sextants, octants, quadrants and chart. These were in general only available on the private market until the establishment of the Hydrographic Office, although the Navy Board and the Board of Longitude did lend some instruments.[4]

This chapter explores how developments both internal and external were shaped by astronomers, mathematicians, navigators, captains, and surveyors. I argue that we should consider additional factors that led to widespread chronometer use at sea, rather than just considering this as a matter of supply and demand. Chronometers had been introduced and used on Royal Navy vessels during the last decades of the eighteenth century. Although they were perceived as beneficial to navigation, problems concerning their use remained. Practical experience of chronometers helped officers evaluate the strengths and weaknesses of these instruments and transformed how chronometers were tested on land and used at sea.

The relationship between clockmakers and the Board of Longitude in the late eighteenth century was characterised by tension. Phillips described how in the eighteenth century these tensions were caused by the transition from 'a reliance on the authority of

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[3] Edward J. Dent, *An Abstract from Two Lectures on the Construction and Management of Chronometers, Watches and Clocks . . . delivered before Members of the United Services Institution*, (London, 1842), p. 5 quoted in Alun Davies, 'The Life and Death of a Scientific Instrument: The Marine Chronometer, 1770–1920', *Annals of Science,* 35:5, (1978), pp. 515-516

[4] W. E. May, 'How the Chronometer Went to Sea', *Antiquarian Horology*, 9:6, (1976), p. 644; Yuto Ishibashi, 'A Place for Managing Government Chronometers': Early Chronometer Service at the Royal Observatory Greenwich', *The Mariner's Mirror,* (2013), 99:1, pp. 52-66,

master in the [clockmakers'] trade to assess their own skill and the skill of the trade, the new standard set to solve the problem of longitude now seemed to want to move such control from the trade, to institutions and personnel associated with the state'.[5] The new standards were astronomical ones; control lay solely in the hands of astronomers, predominantly Greenwich ones. The problem was that chronometers remained inherently unreliable, and thus difficult to use.

The Greenwich Premium trials, instigated in 1822, were established to encourage chronometer makers to improve their instruments. The best performing instruments were guaranteed purchase by the Admiralty at premium prices. The Admiralty's plan was to establish a performance-based testing system, allowing them to select the best performing instruments for the growing number of scientific expeditions being increasingly carried out by Royal Navy officers. Supplied with a larger number of these quality-controlled instruments, expeditions were charged with measuring meridian distances only, an emerging chronometric practice intended to benefit hydrographic surveying.

To assume that higher production numbers and the subsequent reduction in price was the only reason the chronometer went to sea implies a degree of closure, in the instrument and in its use. Technological closure or stabilisation, according to a constructivist view of technological systems, implies that 'a consensus [has emerged] that a problem [arisen] during the development of technology has been closed'.[6] In relation to chronometers, this would imply that the problem of variations in rate, or at least the cause, had been solved. This chapter will show that for chronometers this was not the case. A more nuanced view can be gained by examining the chronometer from the perspective of different user groups

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[5] Eóin Edward Phillips, *Making Time Fit: Astronomers, Artisans and the State, 1770-1820,* Unpublished PhD, University of Cambridge, (2014), p. 50

[6] Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch, 'Introduction', in: *The Social Construction of Technological Systems; New directions in the Sociology and History of Technology,* Wiebe E. Bijker, Thomas P. Hughes, and Trevor J. Pinch, eds. (Cambridge, Massachusetts: The MIT Press, 2012), p. 6

over time, since, 'closure and stabilisation . . . are not isolated events'.[7] This theme runs throughout the thesis, as there are many aspects to examine to understand the role users played in the stabilising the technology. This chapter specifically examines the problems users faced.

Section one examines the issues that naval officers and astronomers encountered in their use of chronometers at sea. Because of the complicated mechanism of the instruments, it was not always clear what was the cause of reported problems and solutions. Accordingly, solutions varied: users did not always agree on how to mitigate the problems experienced at sea. The problem in general was one of trust, or more often, a lack of trust: in the instrument itself, in the operator and in the method of use. Tensions occurred at sea (and on distant shores), where astronomers introduced these new techniques that required additional skill and knowledge that did not always work well with practices already established in traditional navigation and the aims of these practices did not always align. Although this section focuses on the period prior to the case studies examined in this thesis, it gives a clear picture of the issues that users faced using their chronometers during the early nineteenth century and how they considered dealing with them.

Section two considers the role played by the state, institutions and societies in promoting and supporting chronometry at sea. I examine the role of astronomers, mathematicians and the Premium Trials in stimulating improvements in the mechanism of chronometers. This is to show how the technological development of chronometers continued to be influenced not only by clockmakers but also by their users, the Royal Observatory and the Hydrographic Office and how this led to the chronometer trials at the Royal Observatory. As a result, questions concerning the reliability and thus the trust, placed in an instrument, transferred from the clockmakers to the astronomers at Greenwich.

[7] Bijker, Hughes, Pinch, 'Introduction', p. 7

Sections three, four and five together consider the implications of the above to the individuals operating within these structures as they were issued with chronometers for different expeditions. A consequence of the Premium Trials was a stock of chronometers with a clear hierarchy: chronometers that won the annual premium were considered better than others. This had several implications. These chronometers were reserved for those voyages, and officers, with a high standing. The social status of these officers thus granted them access to resources that were denied to others. Being supplied with what were considered 'good' instruments had a direct effect on how trustworthy officers considered their instruments to be, the more so if the device in question had proven reliable on a previous voyage. Questions of trust, authority, hierarchies of instruments and methods are considered throughout these sections. Section three examines the aims of William Edward Parry's Arctic expeditions and the continuing role of astronomers who continued to shape on board practices and how the reliability of the chronometers was evaluated. Section four considers a new approach at sea where meridian distances where measured by larger numbers of chronometers. These expeditions show the relationship between astronomical and chronometrical measurements. I also show how these methods were perceived by both the Admiralty and the Board of Longitude as they discussed the best scheme to measure the longitude of Funchal in Madeira. Like chronometers, not all methods were considered equal. Section five considers William Fitzwilliam Owen's survey of the East African Coast, which reveals uncertainty and confusion surrounding the issuing of chronometers. Owen was not able to access the same resources as those commanding voyages of a more scientific nature and thus had to rely on stringent methods and procedures to gain credibility for the longitudes he produced.

Instruments under investigation: trials and tribulations

The new navigational techniques for determining longitude at sea were tested on voyages of exploration following their introduction in the 1760s. Naval captains and astronomers worked together, testing and trialling these technologies and methods, although this did not occur without challenges.[8] The new techniques and instruments required integration within established navigational practices. Tensions were 'caused by the attempts of naval officers to hold on to traditional forms of understanding their skill and status against the ambitions of astronomy and practical mathematics to transform and regulate those traditions'.[9] In their attempts to establish these practices, the Board of Longitude appointed astronomers to instruct and discipline the crew on naval expeditions. Each astronomer received a set of written instructions compiled by Astronomer Royal Nevil Maskelyne.[10] Particularly in the voyages of the late 1760s and early 1770s, astronomers' work was more suited to astronomical observation on distant shores, rather than assisting in navigational practices that the crew could perform without them. Astronomers like William Wales, (appointed by Maskelyne and the Board of Longitude to Cook's second voyage of exploration on board HMS *Resolution*) thus had to promote themselves by emphasising the importance of accuracy within navigation. More significantly, they had to show that astronomers themselves had the authority required to evaluate this.[11] This requirement for accuracy was not shared by all, and even James Cook thought that inaccuracies in the longitude would not 'much effect either Navigation or Geography'.[12] But by the nineteenth century, this view was changing;

[8] Phillips, *Making Time Fit*, See Chapter 3: 'The States Astronomers', pp. 114-163
[9] Ibid, p. 16
[10] Phillips, *Making Time Fit*, pp. 136-140; Rebekah Higgitt, 'Equipping Expeditionary Astronomers: Nevil Maskelyne and the Development of 'Precision Exploration', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), pp. 16-36
[11] Francis Lucian Reid, 'William Wales (ca. 1734-1798): Playing the Astronomer', *Studies in History and Philosophy of Science,* 39, (2008), pp. 170-175
[12] James Cook quoted in Reid, 'William Wales (ca. 1734-1798): Playing the Astronomer', p. 172

instrumental precision and accuracy transferred from the domain of astronomers and observatories to the emerging group of scientific naval officers.[13] The early Admiralty Hydrographers, Alexander Dalrymple (1737-1808) and Thomas Hurd (1747-1823), saw the potential benefit that chronometers could bring to Admiralty charts.[14] Combined with astronomical observations, accurate chronometer data could be accumulated at the Hydrographic Office, to improve the points of longitude on which accurate charts depended.

These early decades of chronometer use at sea thus proved two things: first, chronometers were a beneficial addition to navigation; second, they could never be completely relied upon. During the late eighteenth century, neither the competence of users, nor the reliability of the instruments, could be guaranteed. Although most early users praised their timekeepers, they were also very aware of the ease with which an instrument could malfunction or slip into a 'state of disrepair'.[15] Chronometers can be said to 'keep' longitude as opposed to 'finding' it. In this sense, astronomical observations such as lunar distances or Jupiter's Satellites would 'find' or establish the longitude of a place. A chronometer could not do this. Rather, it kept an account of the time progressed since departure. If it malfunctioned or stopped, the longitude was lost. Reliability was fundamental, but problematic. Variations in temperature were a known cause of disruption, so temperature compensation was a crucial part of the instrument's design. It was very difficult however, to determine the effect of temperature variations, specifically as there was no way of judging if the internal, delicate mechanism was compensating correctly. Keeping an account of the daily comparison of the chronometers, assuming that more than one had been issued, and noting any potential

[13] Randolph Cock, 'Scientific Servicemen in the Royal Navy and the Professionalisation of Science, 1816-55, in: *Science and Beliefs, From Natural Philosophy to Natural Science, 1700-1900*, Matthew D. Eddy, David M. Knight, eds. (London: Routledge, 2005), pp. 95-112

[14] Adrian Webb, *The Expansion of British Naval Hydrographic Administration,* Unpublished PhD, University of Exeter, (2010), p. 187

[15] Simon Schaffer, 'Easily Cracked: Scientific Instruments in States of Disrepair', *Isis,* 102, (2011), pp. 706-717

causes of disruption (temperature, barometric pressure, unfavourable passages) contributed to the growing understanding of how these instruments fared at sea. But this was not always done, or if done, done systematically. As a result, by the early 1800s there was no consensus as to what exactly caused a chronometer to malfunction, and thus no guidelines on how to prevent this from happening. Human error was inevitable, and many problems could be down to mismanagement of the instruments. One captain, when asked 'by what violence' his chronometer was damaged, admitted that he accidentally dropped it whilst winding, 'though not [through] carelessness or inattention'.[16] He was cautioned to report it in future and to be more careful. In another case, a lieutenant was charged for a chronometer repair previously under his care.[17] Other, less harmful, problems arose when the user forgot to wind the instruments and they stopped, an oversight that was surprisingly common.

Human error was only one cause of malfunction, and at least it was one that was relatively easy to notice. But how was one to know the instrument was performing correctly? Sudden changes in rate could indicate internal problems, but if these changes were gradual, they were harder to detect and could result from a number of causes. Early users were aware of these problems and guidelines appeared in publications like the *Naval Chronicle*. In 1799, for example, Joseph Whidbey, a captain who gained early chronometer experience with Captain George Vancouver on board *Sans Pareil,* advised readers that 'when a timekeeper is received on board a ship, the greatest care should be taken to have it immediately secured in some convenient place in the cabin: where it may be the least liable to be moved during the voyage; it should never be touched but at the time of winding up, which ought to be at noon, and then with the greatest care, particularly avoiding circular motion'. This advice, he

[16] Frederick Bullock to John Barrow, February, 1827. TNA, ADM 1/2794
[17] Admiralty Digest, Mathematical Instruments, 1827. TNA, ADM 12/248

wrote, was considered unnecessary by the makers, but as a user, he found 'the above precautions necessary'.[18]

That not everyone agreed is evident from a pamphlet of 1807 published by John Warren (a captain in the East India Company and temporary astronomer at the Madras Observatory). Warren stated that carrying the instruments from the ship to the observatory had no effect on the rates of chronometers, and, more importantly, that observations taken on shipboard with a sextant could never match the superior observations of the observatory. As a result, he argued, a more accurate rate could be achieved only on shore, at the observatory. These findings were based on an experiment he made with three chronometers (two box-chronometers and one pocket chronometer), where he conveniently blamed any alteration of rate on 'bad watches' or concluded that motion was not the cause.[19] Even as late as 1834, the firm Parkinson and Frodsham communicated on the subject, claiming that transporting chronometers should not alter their rates, and the idea that they did would 'lead persons unacquainted with the subject to form very erroneous notions as to the degree of perfection which the art of chronometer-making has reached'.[20] James Frodsham further argued that *'our Chronometers* are not subject to the change of sea and land rates (which would render them useless for navigation) as stated to exist in the Chronometers of Messrs. Arnold & Dent'.[21] This should be seen for what it was: a prolonged marketing campaign started by the firm in 1819. Considering that the rates of chronometers were problematic, and remained so, the comment that they would be useless for navigation is interesting. It is all the more remarkable because despite this 'uselessness', chronometers came into

[18] G. W. Nockolds, 'Early Timekeepers at Sea: The Story of the General Adoption of the Chronometer Between 1770 and 1820', *Antiquarian Horology*, 4/5, (1963), p. 149
[19] Nockolds, 'Early Timekeepers at Sea', p. 150
[20] James Frodsham, 'On the Sea and Land Rates of Chronometers', *American Journal of Science and Arts,* 26:1, (1834), p. 121
[21] Ibid, p. 121

widespread use. And it was precisely because of this fact and from the difficulty of ascertaining a rate on board a ship that Robert Wauchope (1788-1862), a naval officer who is credited with the invention of the time-ball, corresponded with Barrow in 1824 on the subject of time signals. Wauchope's plan was to simplify the method of chronometric longitude by providing the observer on board with a visual time signal from shore. This would achieve two things. The first was that the chronometer need not be removed from the shore to the ship: thus, a shipboard rate would be acquired. Secondly, this would reduce the time required to establish a rate through celestial observations. Without judging the rights and wrongs of contemporary debates over whether or not the rates differed between ship and shore, two things are clear: a significant number of users found establishing a rate problematic, and the relationship between the ship and the shore (or observatory) could not be broken.

If a faulty mechanism was not to blame for inaccurate readings, what was? What was under discussion was the effect to which variations in temperature, the movement of chronometers, their incorrect handling and their improper storage could have on them. While some of these problems could be addressed through regulations and guidelines, others could not. One of the biggest debates was over the question of magnetism, and whether or not it affected chronometers. Brooks' examination of the publications and experiments conducted between 1798 and 1834 on this subject allowed him to compare contemporary debates to determine what effect, if any, local or terrestrial magnetism was thought to have on chronometers.[22] Brooks looked at contributions from several individuals. Samuel Varley, a watch and instrument maker, initiated the discussion in 1798 after experimenting with steel and gold balances in various positions in the vicinity of a magnet. He concluded that

[22] Randall C. Brooks, 'Magnetic Influence on Chronometers, 1798–1834: A Case Study', *Annals of Science*, 44:3, (1987), pp. 245-264

magnetism altered the rate of a chronometer depending on its position. George Fisher (1794-1873), the astronomer appointed to Parry's second voyage, produced a paper detailing the effects of magnetism on chronometers in 1820. Fisher's paper was based on his experiences as astronomer on board HMS *Dorothea* in 1818 where he was in charge of rating the chronometers. He found that the rates increased whilst sailing in comparison to the rates determined on shore. Fisher blamed the alteration of the rates entirely on the effects of magnetism, rather than the motion of the vessel, as others argued. Peter Barlow, a mathematician and physicist, continued Fisher's experiments in 1822 at the observatory of the Reverend Lewis Evans, situated on Woolwich Common. Like Varley, he used a magnet to determine the influence on a number of chronometers and concluded, just as Varley and Fisher did, that magnetism affected chronometers. Brooks concluded that the research methods applied by these individuals were questionable at best.

Figure 3.1: Mechanism of Arnold 326. George Fisher believed that magnetism would have a detrimental effect on the steel balance (NMM ZAA0067). © National Maritime Museum.

Figure 3.2: One-day chronometer by John Arnold & Son, no 326. This chronometer was the property of George Fisher. He used it whilst serving as astronomer on HMS *Hecla*, 1821-23. (NMM ZAA0067). Betts, *Marine Chronometers at Greenwich*, pp. 268-270. © National Maritime Museum.

My point here is to emphasise that such debates were taking place and to note the effect that had on how users perceived or used chronometers, rather than to evaluate the efficiency of their research methods. The above-mentioned experiments were all based on the assumption that the ship itself was the source of error, due to the iron on board. William Scoresby, Arctic observer and whaler, determined that it was not *local* magnetism, but *terrestrial* magnetism that was to blame for the variations found between land and sea rates.

His paper to the Royal Society of Edinburgh in 1823 detailed not only his conviction of this effect, but also provided three potential remedies: two lay in the hands of instrument makers as they relied on using non-ferrous or non-magnetic materials for balances (as Dent had experimented with glass balance springs) or by eliminating magnetism within the steel balance. The third solution was to mount a pocket chronometer on a compass card in a box, suspended in gimbals, which would keep the instrument aligned to the magnetic meridian.[23] Although Scoresby tested this method himself, there is no evidence that others did.

Others disagreed over the effect of magnetism. William C. Bond, chronometer maker and first Director of the Harvard College Observatory, recorded the land rates and sea rates of 133 chronometers between 1821 and 1829. He concluded that removing chronometers from the ship did not lead to a gain in their rates, and although it did produce some variation, this was 'so minute, as to be within the limits of error to which Chronometers, in their present state, are liable on shore'.[24] The conclusion Brooks draws, on examining Bond's paper, is that 'Bond was counting "apples and oranges" in making such computations' and that all he proved was that 'given a large number of chronometers, there is no systematic difference, either gaining or losing in the sea – land rates'.[25] This was exactly the point Ezekiel Walker had made to the Board of Longitude in 1783. Ezekiel Walker (1741-1834) from King's Lynn (best known for his reflector designs for lighthouses) corresponded with the Board and with Maskelyne on this issue. Since the chronometer was unreliable on long voyages, he suggested using five or six chronometers from which a mean longitude would be deduced. This would give greater accuracy to the result even after three or four months. This had the additional advantage that the other chronometers could be used if one stopped to restart it or to detect irregularity in any of the instruments, allowing users to reject its rate in the mean.

[23] Brooks, 'Magnetic Influence on Chronometers', pp. 253-254
[24] William Bond quoted in Brooks, 'Magnetic Influence on Chronometers', p. 256
[25] Brooks, 'Magnetic Influence on Chronometers', p. 256

Walker provided examples of the comparison of three Arnold chronometers (Nos. 36, 51, and 59) over a thirty-day period and between one Arnold (No. 86) and two Mudge timekeeper's ('green' and 'blue') over a three-month period: 'From these examples we may see . . . how regularity rises out of irregularity; the error of one time-keeper correcting that of another . . . and as the number of time-keepers increases, the error will decrease, until it be almost annihilated'.[26] As with other contributors to the debate, cost was seen as the only objection, although Walker argued, as did others, that the cost of acquiring the chronometers was of 'no proportion' to the security it enabled.[27] The Board did not approve his recommendation, but not because it was a bad idea. Maskelyne commented that Walker's proposal was 'certainly very judicious, being founded upon the same principles as the advantage arising from taking a mean of a number of observations in practical astronomy'.[28] Unfortunately for Walker, who was writing in the hopes of claiming some reward for the idea, Maskelyne continued that 'it is at the same time so very obvious that it cannot be considered as new, or containing any great degree of merit; indeed I have myself heard it often suggested by different persons in conversation upon the use of time-keepers'.[29] Maskelyne also pointed out that this method would only remove larger errors, not smaller ones.

By the 1820s, chronometers were increasingly used at sea: on surveying voyages, voyages of exploration, commercial merchant exchanges and for routine navigation. Attention to detail in the use of the instruments was wholly dependent on the purpose of the voyage. Commercial voyages, looking to shorten their voyage by relying on the chronometers, could disregard gradual changes in rate as soon as they reached their destination or a port along the way. There, a new rate would be established for the next part

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[26] Anonymous, *A Journal of The Natural Philosophy, Chemistry and The Arts,* Vol. 8, 1804, pp. 65-70
[27] Ibid, pp. 65-70
[28] Report by the Astronomer Royal, 17 December, 1783. CUL, RGO 14/10, f. 215v
[29] Ibid, f. 215v

of the voyage. Thus, for many users, the chronometer fulfilled the purpose that it was put to, mainly helping them get to their destination more quickly and in safety. Despite this, a growing number of users saw benefit could be gained from the instruments if they could be made more reliable and the standardisation of practices could lead to the accumulation of data.

Astronomers, mathematicians and the Greenwich Trials

The chronometers that went to sea in the early nineteenth century were of a basic design that remained almost the same for the next 125 years.[30] Despite this apparently successful technological achievement, trialling and testing the instruments remained an essential requirement. Not many people would dispute that a chronometer was valuable in navigation, but they still had the potential for considerable inaccuracy. As to the cause of inaccuracy, which was generally put down to an unpredictable acceleration or retardation of rate, this remained unsettled. In 1804 William Nicholson, chemist and inventor, published a letter in the *Journal of Natural Philosophy, Chemistry and the Arts*, which he also edited. The writer of the letter was John Haley (probably the son of clockmaker Charles Haley, one of the experts appointed to report on the marine timekeepers made by Thomas Mudge in 1793). The letter concerned the matter of irregularities in chronometers. Haley's opinion was that chronometer makers too easily blamed external factors for affecting the rate of their instruments, rather than any 'mechanical cause': this, he pointed out, did not encourage mechanical improvements of the instrument.[31] Arnold and Earnshaw dominated the market

[30] Rupert Gould, *The Marine Chronometer: Its History and Development,* (Woodbridge: Antique Collecters' Club, 2013), p. 133; Jonathan Betts, *Marine Chronometers at Greenwich, A Catalogue of Marine Chronometers at the National Maritime Museum, Greenwich*, (Oxford: Oxford University Press, 2017), p. 66

[31] John Haley, 'Experiments on Chronometers', *Journal of Natural Philosophy, Chemistry and the Arts,* 8, (1804), pp. 46-57

during this time and their chronometers were those tested upon the exploration voyages in the late eighteenth century. These chronometers did not always perform well and so the Admiralty needed to find a means of valuing individual instruments rather than remaining dependent on the makers' reputation. There was no point in buying up a stock of chronometers if the instruments proved unreliable. But the Royal Navy would prove a viable market, one which the junior Mudge attempted to tap into by requesting 'permission to become Chronometer-Maker to the Royal Navy'.[32] As his chronometers were no better than those of Arnold and Earnshaw, and costed twice as much, the Board refused his request. Although there was a willingness from the Royal Navy to buy chronometers and chronometer makers had succeeded in lowering the price to between sixty-five and eighty guineas, the process of setting up a valuation scheme that favoured performance over reputation still took two decades to accomplish.

In 1805, William Marsden (1754-1836), First Secretary to the Admiralty, outlined a plan in which chronometers would be tested, both on land and at sea, before they were purchased by the Admiralty, at prices determined by their performance. The plan was comprehensive. Chronometers would be trialled for three months by the 'land Tryer' on shore, who would keep 'a regular account of the going of each watch in different positions and of the effects of heat & cold on each'.[33] This land trial had two underlying purposes: it would determine which chronometers should be selected for a further trial at sea and, in the case of further trial, it determined what the rate should be. The plan further detailed exactly how the chronometers should be transported; that the ship should be sufficiently outfitted to receive the instruments (and if not, that 'objections' and 'remedies' should be reported); when and how the watches should be wound and compared; and, finally, how astronomical observations

[32] May, *How the Chronometer went to Sea*, p. 644
[33] William Marsden to George Gilpin, 7 March, 1805. CUL, RGO 14/23, ff. 6r-10v, quotes on f. 7r and f. 6v respectively.

should support the trial. The level of accuracy achieved by each chronometer on the sea trial would determine the value, and thus the purchase price, of each instrument. Marsden listed these as follows:

- 100 guineas: if during the shore trial the monthly mean did not exceed 1.45 seconds and at sea the error did not exceed more than four minutes in time or one degree of longitude.
- 80 guineas: if during the shore trial the monthly mean did not exceed 2 seconds and at sea the error did not exceed more than six minutes in time or one-and-a-half degrees of longitude.
- 60 guineas: if during the shore trial the monthly mean did not exceed 2.15 seconds and at sea the error did not exceed more than eight minutes in time or two degrees of longitude.[34]

Despite this detailed plan, one crucial element was missing. Marsden left blanks in the document regarding where the journals and records relating to the trial should be deposited and who should oversee the trial. This indicates that this was an element requiring further thought and suggests that Marsden may have expected the Board of Longitude to decide this (figure 3.3).

[34] William Marsden to George Gilpin, 7 March, 1805. CUL, RGO 14/23, ff. 9r – 9v

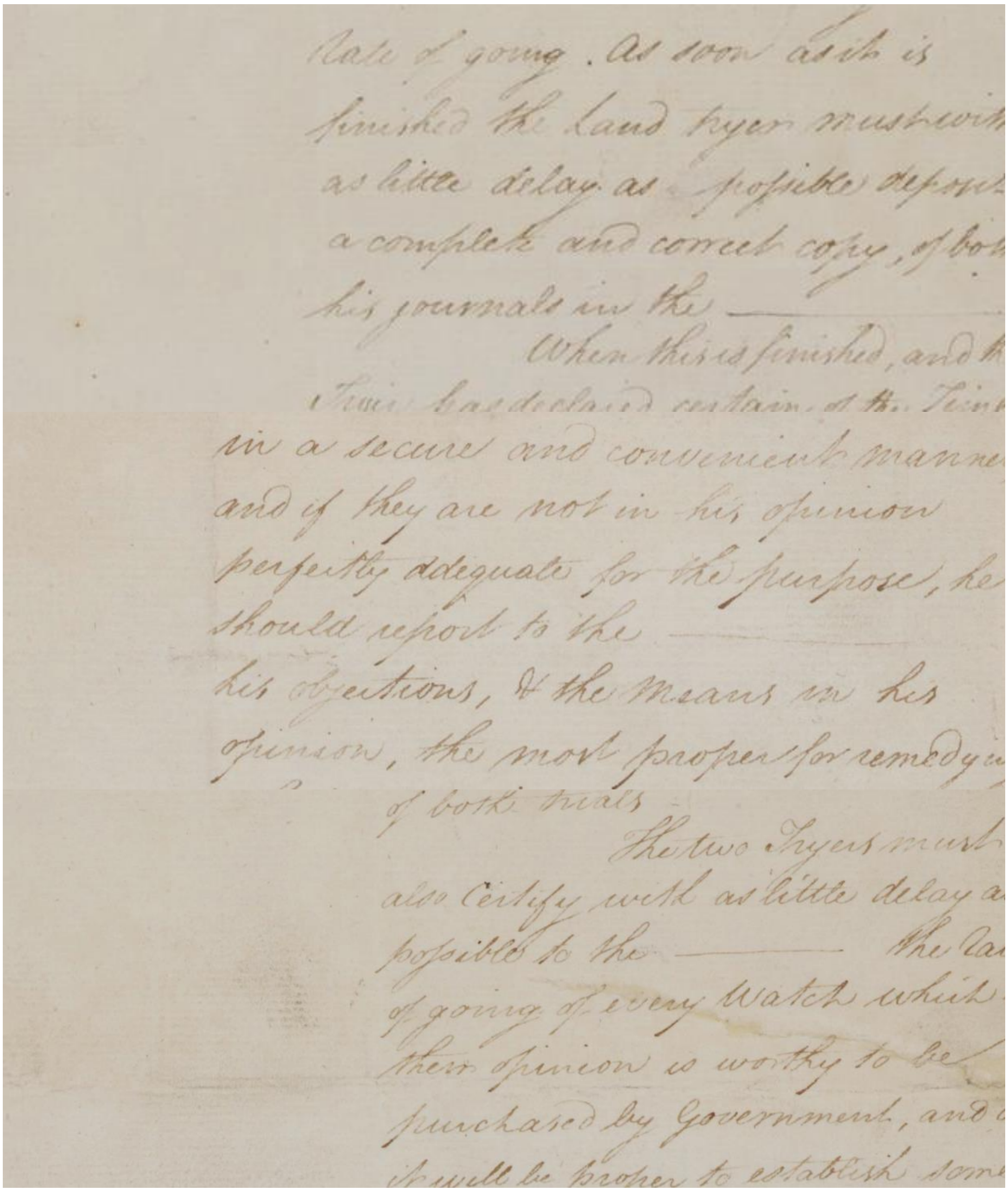
Rate of going. As soon as it is
finished the Land Tryer must with
as little delay as possible deposi
a complete and correct copy, of bo
his journals in the ———
When this is finished, and th
[illegible]
in a secure and convenient manne
and if they are not in his opinion
perfectly adequate for the purpose, he
should report to the ———
his objections, & the Means in his
opinion, the most proper for remedy
of both trials
The two Tryers must
also Certify with as little delay a
possible to the ——— the Ra
of going of every Watch which
their opinion is worthy to be
purchased by Government, and
it will be proper to establish some

Figure 3.3: Marsden’s black sections relating to chronometer trials. CUL, RGO 14/23.

If any one reason should be underlined as to why the testing and issuing of chronometers was unregulated at the start of the nineteenth century then evidence suggests that we should point to a lack of administrative oversight on the Admiralty’s part. Masters of Royal Navy ships were responsible for the purchase of their own mathematical instruments and charts. Some specialist equipment could be issued by the Navy Board or the local dockyard official, a category to which the chronometer belonged. But these were not standard issues and stocks were low.[35] Alexander Dalrymple wrote to the Admiralty in 1807 proposing that officers also be issued with 'chronometers, nautical almanacs, a protractor and a 'graduated Semi circle of transparent Horn''.[36] Before Hall picked up the call for a systematic method of trialling chronometers at sea (see the epigraph which begins this chapter), an anonymous captain wrote in 1812 to the *Naval Chronicle*, adding his voice to calls to the Admiralty to supply officers with instruments. He claimed that shipwrecks and losses at sea could be avoided if the officers had the means to determine the longitude. He argued that the cost of supplying chronometers, sextants and barometers for a period of ten years would amount to no more than £95,000 for the whole navy (0.05% of the total expenditure of £190 million over a ten-year period). It is worth emphasising that the author requested not just two chronometers per ship, but also three sextants and two barometers.[37]

Thomas Hurd was instrumental in establishing a more central and organised distribution depot, although this did not appear overnight. In regards to the chronometer, the Navy Board had established a stock of chronometers at the Naval College in Portsmouth, under the charge of James Inman (1776-1859), astronomer and Professor of Nautical Mathematics at the College. Chronometer stocks were low, and many requests were refused.[38] These duties were transferred to Hurd in 1818, when he was officially appointed superintendent of the chronometers, although he had been involved in these duties since

[35] Webb, *The Expansion of British Naval Hydrographic Administration,* p. 295
[36] Alexander Dalrymple to Pole, 10 October 1807. TNA, ADM1/3523, quoted in Webb, *The Expansion of British Naval Hydrographic Administration,* p. 295
[37] John Malham, *Navigation Made Easy and Familiar,* (London: S. Crowder and B. C. Collins, 1790), p.263; *Naval Chronicle*, Vol. 27, (1812), pp. 121-122
[38] Inman had sailed with Matthew Flinders on board HMS *Investigator,* replacing the astronomer who had suffered from seasickness. He published *Navigation and Nautical Astronomy for Seamen* in 1821. May, 'How the Chronometer Went to Sea', pp. 638-63; Nockolds, 'Early Timekeepers at Sea', pp. 148-152

1809.[39] His duties, described by himself as 'a subject of serious consideration', and by virtue of being 'their public accountant', included keeping records of all associated costs (purchase and repair) and registering the movements between stores, ports, makers and ships.[40] The instruments (mostly Arnolds') were in short supply. As soon as a chronometer was purchased or returned from repair, it was issued to a ship from the Royal Naval College in Portsmouth. Rates and errors of the timekeepers were provided either by the respective maker or by James Inman at the Royal Naval College. Stocks at the Naval Yard in Plymouth were problematic, but it was again thanks to Hurd's efforts that an agent was set up there: Mr. Cox held a small stock of Arnold chronometers, kept an account of their rates and notified Hurd when an instrument was issued to a ship. Despite these efforts, between 1815 and 1820, many requests for chronometers were still being refused.[41] Gradually, as stocks increased, more applications for chronometers were accepted. When the superintendence of the instruments was transferred to the Astronomer Royal, John Pond, in 1821, the number of chronometers had increased from thirty to 130.[42]

It is important to understand why these duties were transferred to the Royal Observatory as a site, under the care of the Astronomer Royal as an authority, especially since Hurd was opposed to the move. Hurd's main objection concerned the additional transfer that chronometers would be subject to. Hurd argued that this was 'likely to prove

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[39] Various sources list different dates for the transfer of the chronometer duties to the Hydrographer. Ishibashi, Nockolds and May both claim it was around 1810, but list no sources. Webb lists the date as 1809. The issue may be resolved if the duties were transferred to the Hydrographic Office around 1810, but a superintendent not appointed until 1818. Webb, *The Expansion of British Naval Hydrographic Administration,* p. 295. The Admiralty Digest also states 1818 (TNA, ADM 12/193, tab 57a Board of Longitude)

[40] Letter from Thomas Hurd to John Pond, Hydrographic Office, Admiralty, 3 September, 1821. CUL, RGO 5/229, f. 4r

[41] Admiralty Digest Books: TNA, ADM 12/174, ADM 12/180, ADM 12/185, ADM 12/189, ADM 12/194 see tab 98.4 'Mathematical Instruments'.

[42] For a more detailed account of the period under Hurd's supervision, and the management of the chronometers under Pond at Greenwich, see Webb, *The Expansion of British Naval Hydrographic Administration,* and Ishibashi, 'A Place for Managing Government Chronometers'.

more injurious than beneficial to the service' as well as causing 'many inconveniences to the Board'.[43] One reason for the transfer was the change in supervision of the Royal Observatory itself, which since its establishment in 1675 had been in the hands of the Board of Ordnance. Due to a lack of decent funding from this body, the Astronomers Royal often had to depend on additional funding from the Admiralty and Treasury. In 1816, the Board of Visitors (mostly comprised of council members of the Royal Society) recommended the transfer of supervision to the Admiralty with a view 'to improve administrative procedures, astronomical efficiency, and navigational science'.[44] This also allowed the Admiralty to set up a land-based trialling system for the instruments, as Marsden had first suggested in 1805.

Before the Greenwich trials, the Admiralty and Board of Longitude were wholly dependent on the authority of chronometer makers when it came to judging the merits of a timekeeper.[45] Although chronometer makers could rely on their status and authority to sell chronometers through the private market, a state-funded stock of instruments required independent quality control. Hurd may have provided good administration, but he could not perform this latter aspect. Prior to becoming the official testing centre for chronometers, the Royal Observatory and the Royal Society had been performing chronometer tests for those timekeepers sent on board early voyages of exploration. Maskelyne had conducted trials between 1770 and 1790 for the Board of Longitude to test the accuracy and reliability of the chronometers. This had sometimes caused tension between the Astronomer Royal and makers such as Harrison, Arnold, and Mudge. The Royal Observatory was not necessarily the obvious place for trialling and issuing chronometers. Hurd was very keen to fulfil the latter function, and Inman at the Royal Naval College was also capable of managing a depot at one of the biggest dockyards in the country. In addition, Henry Browne's house at Portland Place

[43] Hurd quoted in Webb, *The Expansion of British Naval Hydrographic Administration,* p. 304
[44] Ishibashi, 'A Place for Managing Government Chronometers', pp. 54-55
[45] Phillips, *Making Time Fit*, pp. 62-69

in London was used to test the chronometers issued to the polar voyages in 1818 and 1819, under the expertise and authority of Captain Henry Kater.[46]

In 1821, the responsibility did become that of the Royal Observatory, and did so as a result of Maskelyne's management of the site between 1765 and 1811. Within this period, he transformed the Royal Observatory into a 'truth-spot', a place Gieryn describes as a 'delimited geographical location that lends credibility to claims'.[47] The Observatory's credibility lay not in the bricks and mortar, nor the instruments and observers, nor even the Royal title; but rather in Maskelyne's strict regime of discipline and regulation.[48] If the Admiralty in 1820 was looking for a location from which to test and issue chronometers, then Maskelyne had ensured that this place should be Greenwich. Numerous observatories were established in eighteenth-century Britain, many equipped with superior instruments and better astronomical practices. But what Maskelyne emphasised was 'the need to demonstrate at all times the effective management and maintenance of clocks and other instruments'.[49] Maskelyne 'described, lobbied for and then implemented a set of managerial, publishing, and epistolary practices that would secure his vision of British state-sponsored astronomy co-ordinated from Greenwich'.[50] By this time, the Royal Observatory was also funded by the Admiralty.

Transferring the duty to the Astronomer Royal John Pond in 1821 thus finally implemented Marsden's plan to properly test chronometers when securing them for the Admiralty, and helped further establish the Royal Observatory at the centre of state-

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[46] List of government chronometers, UKHO, MLP 82; Sophie Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, Unpublished PhD, University of Cambridge, (2014), pp. 97-100
[47] Thomas F. Gieryn, 'City as Truth-Spot: Laboratories and Field-Sites in Urban Studies', *Social Studies of Science,* 36:1, (2006), p. 29
[48] Nicky Reeves, 'Maskelyne the Manager', in: *Maskelyne, Astronomer Royal*, ed Rebekah Higgitt, (London: National Maritime Museum, 2014), pp. 97-123
[49] Reeves, 'Maskelyne the Manager', p. 104
[50] Ibid, p. 97

sponsored nautical science. The trials went further than this, as they also realised John Haley's point that to improve the chronometers makers would need an additional incentive, as can be seen in the official announcement in the *London Gazette* in June 1821:

> The Lords Commissioners of the Admiralty, being desirous of increasing the number of chronometers for the use of his Majesty's Navy, and of encouraging the improved manufacture of that important article, do hereby give notice, that a depot for the reception of chronometers is opened at the Royal Observatory of Greenwich, where the makers will be permitted to deposit their chronometers, in order to their being tried, and ultimately purchased for the use of the navy, or of being disposed of by the proprietors to private purchasers. And, for further encouragement, their Lordships will purchase, at the end of each year, the chronometer which shall have kept the best time, at the price of 300£, and the second best at the price of 200£, provided that there have been above ten chronometers in the competition . . . The other chronometers their Lordships may purchase, as they may think proper, at such sums as may be agreed upon with the makers, and their Lordships have reason to expect, that their annual rate of purchase, for some years to come, will be not less than ten chronometers in each year.[51]

After its announcement, the first trial ran from February 1822 until January 1823. The Astronomer Royal and the Board of Longitude were tasked with overseeing the trials. John Wilson Croker (1780-1857), First Secretary to the Admiralty from 1809 to 1827, announced in the *London Gazette* the purchase of Barraud 957 for £300 and Pennington 154 for £200. The announcement included a paragraph on how the rates would be computed and the limits within which they should fall. For the trail commencing in 1823, these limits were set at under six seconds for the first prize and at under ten seconds for the second prize.[52]

Following the first-year trial, the initial method of determining how the rate should be calculated and within which limits they should fall was judged by a committee of the Board of Longitude (John Pond, William Hyde Wollaston, Captain Kater, Thomas Colby, John Herschel, Thomas Young). Based on the results achieved by this trial, they immediately narrowed the limits for the first and second prizes. The limit was based on the greatest

[51] *London Gazette,* 26 June, 1821.
[52] John Wilson Croker, Admiralty Office, *London Gazette*, 28 April, (1823) p. 707

variation found within one month of chronometer rating, which for the purposes of the trial was doubled. Barraud's chronometers achieved a result of 11.29/10.40, the smallest that year, and Pennington, 12.87.[53] For the next year's trials, the commissions '[begged] leave to suggest that for rewards to be adjudged in future, it be a condition without which the first reward cannot be claimed, that the sum of the mean monthly variations added to twice the variation of the mean monthly rates, shall not exceed eight six seconds and that for the second prize, it shall not exceed twelve ten seconds'.[54] Young sent the report to astronomers and mathematicians in Cambridge and Oxford requesting their opinions on the proposed method.[55] Amongst the recipients was Thomas Turton, then Senior Wrangler and Lucasian Professor of Mathematics at St. Catherine's College, Cambridge. Turton approved of the proposal, but suggested that 'to guard, in some measure, against sudden changes, could any limit be fixed to the variations of the rate, in two or three successive days?'[56] Three weeks later, Turton added another excluding clause over variations between mean daily rates exceeding a specified amount. Stephen Peter Rigaud, Savilian Professor of Astronomy, and Abraham Robertson, Scottish mathematician and astronomer, both approved of the scheme although they had 'some difficulty in forming an opinion' regarding the limits for the prizes.[57] William Lax, Lowndean Professor of Astronomy and Geometry at Cambridge, approved of the plan, although his colleague Robert Woodhouse pointed out potential errors. Woodhouse, Plumian Professor of Astronomy at Cambridge, formulated a different

[53] The calculation for example Pennington was as follows: greatest variation in one month (+5,08) + least variation in one month (-0.05) = difference (5.13). This difference was doubled (10.26) and the mean of the variations added (2.61) resulting in a trial number of 12.87.
[54] J. Pond, Wm Wollaston, Henry Kater, Tho. Colby, J. F. W. Herschel, Thomas Young, *Report of a Committee of the Board of Longitude respecting the Mode of Trail to be adopted for Chronometers,* Admiralty, 25 February, 1823. CUL, RGO 14/23, f. 70v: The scorings through are the original emphasis in the manuscript.
[55] Turton, Professor of Mathematics at Catherine's Hall; A. Robertson and S. P. Rigaud, Professors of Astronomy and Geometry respectively at Oxford; W. Lax, Professor of Astronomy at Cambridge; R. Woodhouse, Plumian Professor of Astronomy at Cambridge.
[56] Thomas Turton to Thomas Young, Catherine Hall, Cambridge, 19 April, 1823. CUL, RGO 14/23, f. 73r
[57] A. Robertson and S. P. Rigaud, Oxford, 22 April, 1823. CUL, RGO 14/23, f. 74r

calculation that would detect irregularities in the daily rates that would otherwise go unnoticed.[58]

The importance of mathematics and of mathematical reasoning in relation to chronometry must not be underestimated. As described earlier, Maskelyne had pointed out that Walker's plan (of using multiple chronometers to average out errors) was not novel and that it was already applied to practical astronomy. The problem with chronometers was that their rates were liable to an irregularity that was unpredictable. In the case of the chronometer trials, mathematics might provide a solution to this problem by defining a way in which all types of irregularity could be identified; be they daily, monthly, regular or irregular fluctuations. But even mathematics cannot 'magic' regularity out of irregularity. The trials suggested by the Board required the advice of the most prominent mathematicians and astronomers. Thus, it is clear that even on land, astronomers and mathematicians struggled to determine the most effective method of establishing the reliability of chronometers.

Not all credible authorities were supportive of the proposed method. In an 1822 article, James South, astronomer and joint founder of the Astronomical Society, made his view clear. This was apparent from the title 'Observations on the Chronometrical Arrangements now carried on at the Royal Observatory, under the authority of the Lords Commissioners of the Admiralty, tending to shew their Inadequacy to the purpose for which they were designed'.[59] His motive for writing was 'that the acts of public bodies, which have for their object public benefit . . . become fair subjects for private as well as public inquiry'.[60] A good chronometer, according to South, had a uniform rate and would not be affected by

[58] Corrections to a report on chronometers, Robert Woodhouse, not dated. CUL, RGO 14/23, f. 77r
[59] James South, 'Observations on the Chronometrical Arrangements now carried on at the Royal Observatory, under the authority of the Lords Commissioners of the Admiralty, tending to shew their Inadequacy to the purpose for which they were designed', *Quarterly Journal of Science, Literature, and the Arts,* Volume XIII, (1822), p. 211
[60] South, 'Observations on the Chronometrical Arrangements now carried on at the Royal Observatory', p. 211

temperature or by the position of the instrument. South's criticism was that the trials did not test how the chronometers fared in a variety of circumstances. He pointed out that a chronometer 'may go well whilst horizontal, and ill whilst vertical; and *vice versa,* or it may go well whilst in a state of quiescence and ill when put in motion; it may go well when placed in an atmosphere which is temperate, and ill when exposed to extremes of heat or cold'.[61] Although South was known for his critical writing (he was critical of the *Nautical Almanac* and laid 'Thirty-six Charges against the President and Council of the Royal Society'), he had a point.[62] A paper by an unknown author contained in the same volume as the correspondence concerning the chronometer trials raised the same concern: 'no chronometer, however excellent it may have proved, on any number of previous occasions, can, or ought to be implicitly relied on … the principle of the instrument implores this necessity, & as it cannot be removed, other means must be resorted to, to counter act the errors into which it must necessarily lead'.[63]

That the trials to improve the accuracy of the instruments had been successful by 1831 can be seen in attempts by the increasingly narrow limits placed on the rewards: the 'trial number is to be three seconds and a half for the first premium, four seconds and a half for the second and six seconds for the third premium'.[64] After the dissolution of the Board of Longitude in 1828, the oversight of the trials fell under the joint supervision of the Admiralty, the Hydrographer and the Astronomer Royal.[65] The trials were terminated in 1835 as their lordships were 'now satisfied that the instruction with which the system of annual trials of

[61] South, 'Observations on the Chronometrical Arrangements now carried on at the Royal Observatory', p. 215
[62] A. M. Clarke, revised by Michael Hoskin, *South, Sir James (1784-1867), Oxford Dictionary of National Biography*, (online ed.), Last accessed 16 September 2020: https://doi-org.ezproxy.is.ed.ac.uk/10.1093/ref:odnb/26046
[63] Instructions for the use of Chronometers supplied to His Majesty's Ships. Unknown author, not dated. CUL, RGO 14/23, ff. 100r-100v
[64] Francis Beaufort to John Pond, Admiralty Office, 13 October, 1831. CUL, RGO 5/231, f. 64
[65] Waring, *Thomas Young, the Board of Longitude, and the Age of Reform*, pp. 189-190

chronometers and procuring premiums has had its full effect'.[66] Rewards were still offered to encourage improvement in the instruments, specifically ones that reduced the cost of manufacture or those 'by which a greater uniformity of rate can be measured within more certainty under all variations of positions, motion & climate'.[67] One effect that was perhaps not expected was expressed by John Pond (1767-1836) in a letter to Croker. The improved rates of chronometers led to 'fastidious' captains feeling 'extremely mortified if we cannot indulge them with one of superior class'. Pond was thus left with a surplus of 'indifferent ones' useless for any service. He suggested purchasing an additional supply of chronometers because the number of chronometers required at any point in time could not be predicted.[68] During the 1830s, problems arose in the allocations of the premium rewards between the Admiralty, Pond and the chronometer makers, leading Pond to suggest a suspension of the trials.[69] Although the trials were terminated in 1835, a new and similar system was adopted by George Airy in 1840. Airy abandoned the premium reward system but retained the aim: improving the construction of chronometers and the means for judging their merits. Airy 'introduced new methods of rating, the publications of the results and arrangements for trial in heat and cold' and in later reports 'attributed the general improvement in the chronometer to the work done at Greenwich'.[70]

Pond's duties as superintendent of chronometers were not limited to overseeing the chronometer trials. He continued with the duties listed by Hurd: issuing chronometers, keeping an account of their rates and errors, organising repairs when needed, overseeing and regulating supply and stocks at additional depots. The increase in stock at Greenwich led to a heavy burden on the Astronomer Royal. Pond had already commented on the burden

[66] John Barrow to John Pond, Admiralty Office, 9 January, 1835. CUL, RGO 5/231, f. 265r
[67] Ibid, f. 265v
[68] John Pond to John Croker, Royal Observatory, 15 August, 1829. CUL, RGO 5/233, f. 49v
[69] See Ishibashi 'A Place for Managing Government Chronometers'
[70] Jim Bennett, 'George Biddell Airy and Horology', *Annals of Science*, 37, (1980), p. 277

that the trials placed on him, requesting that makers be restricted to sending only one chronometer per year and that Pond should be allowed to select forty of the best instruments after the first month to continue with the trial. Pond complained to Croker that 'the number of Chronometers deposited here on the Annual Trials, have so much increased of late Years, that they very materially interfere with the business of the Royal Observatory'.[71] Inman echoed this, stating that the timekeepers interfered with the duties of his assistants at Portsmouth, adding that the 'Astronomer Royal was made superintendent of timekeepers (which office I do not envy him by any means)'.[72] Edward Walter Maunder would later comment that during this period, the 'excessive development of chronometer business [was], so as practically to swamp the real work of the Observatory, whilst the prices paid for the chronometers at this time were often much larger than would have been the case under a more business-like administration'.[73] Pond had often been absent from the Royal Observatory, particularly in the 1830s, in stark contrast to his predecessor Maskelyne's approach of 'careful managerial attention' and 'constant attendance'.[74] By 1829, the Admiralty again turned to the then Hydrographer (Francis Beaufort) to oversee the management of chronometers issued to ships, although their rating and testing still took place at the Royal Observatory. When George Biddell Airy (1801-1892) became Astronomer Royal in 1835, he noted that a third of the staff's time was taken up in rating chronometers.[75]

Transferring the duties regarding chronometers to the Royal Observatory and establishing the Premium Trials had a significant impact on the development and use of chronometers at sea. The trials encouraged some improvement in the instruments, as can be

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[71] John Pond to John Wilson Croker, Royal Observatory, 16 June, 1827. CUL, RGO 5/233, f. 37v
[72] James Inman to Thomas Taylor, 19 March, 1822. CUL, RGO 5/234
[73] Edward Walter Maunder, *The Royal Observatory Greenwich,* (London: The Religious Tract Society, 1900), p. 101
[74] Reeves, 'Maskelyne the Manager', pp. 108-109
[75] Davies, 'Life and Death of a Scientific Instrument', p. 517

seen by the narrowing of the limits within which first premiums were rewarded. The trials also put the Royal Observatory at the centre of chronometer use at sea. The Longitude Act of 1818 had reorganised the Board of Longitude, transforming it into ‘a scientific department for the Admiralty’.[76] Maskelyne had already been instrumental in testing the new technology for the Board of Longitude. With both the Board and the Royal Observatory now firmly under Admiralty authority, and the transfer of superintendence to the Astronomer Royal, these duties became Admiralty business. This included the issuing of chronometers to captains of Royal Navy vessels. But although Pond was in charge of issuing chronometers, he was only able to fulfil the instructions he was given by the Admiralty. For a captain to be assigned a chronometer he had to apply to the Admiralty, the First and Second Secretaries (Croker and Barrow) then deliberated and if they agreed, Pond would be notified and directed to issue one. The trials had also ended the dominance of Arnold and Earnshaw on the chronometer market. When the trials started in 1821, nine makers made up the total of 130 government chronometers. By 1835, fifty different makers were responsible for the 356 government-owned chronometers.[77]

The establishment of an official depot and testing ground for chronometers had a profound effect on how they were used at sea. Acknowledging both the drawbacks but also the potential of the instruments led to practices that would improve the use of chronometers. The trialling on land gradually led to better instruments. Their use at sea gradually led to standardised methods of use (issues explored in chapters 5-7). As part of this, certain voyages were issued with what were considered the best instruments, which in general meant those with small amounts of variations and a regular rate.

[76] Alexi Baker, ‘Longitude Acts’, *Longitude Essays*, Royal Greenwich Observatory Archives. Last accessed 15 September 2020: https://cudl.lib.cam.ac.uk/view/ES-LON-00023/1
[77] Ishibashi, ‘A Place for Managing Government Chronometers’, p. 63

Parry's three expeditions to find a North-West Passage

The Greenwich Trials are of particular interest for scientific expeditions as the chronometers receiving the premium rewards were often reserved for these expeditions. Parry's three voyages of discovery for a North-West Passage set out before, during and after these changes had taken place and therefore present an interesting case study through which to consider the implication for users.

Parry's voyages were modelled on the preceding expedition of 1818 led by John Ross (1777-1856), on which Parry served as commanding lieutenant on HMS *Alexander*, and Edward Sabine served as appointed astronomer (and thus in charge of the chronometers) on board HMS *Isabella*. The *Isabella* carried seven chronometers, only three of which were government property. Two chronometers were loaned to the expedition by Henry Browne, one was owned by Ross, and the final one was on loan from chronometer makers Parkinson and Frodsham. Parkinson and Frodsham, who, in their own words, 'had devoted a considerable portion of their time and great attention to the improvement of Chronometers, and had spared *neither expense nor exertions* in their endeavours to attain perfection, considered this an opportunity of having one of their principle practically tried'.[78] Parkinson and Frodsham chronometers were adapted specifically for the cold conditions of the Arctic, and, as a result, they became Parry's preferred instruments. This was important as the chronometer was tested in the environment it was adjusted for, thus eliminating one of South's criticisms of the method employed at the Royal Observatory for testing chronometers; namely, that a chronometer might perform well in certain circumstances, but poorly in others. This marketing strategy proved successful, and the firm lent instruments to all subsequent Arctic expeditions and incentivised other makers to loan instruments for

[78] Anonymous, *Chronometers Fabricated by Parkinson And Frodsham: Advertisement, With Testimonials*, (London: Printed by Prittman, 1835), pp. 3-4

testing too. Although chronometer P&F 228 was sent by the makers specifically to test the principles on which it had been adjusted, this was not the case for the chronometers supplied by the Admiralty.

In addition to Ross's expedition, another expedition set out in 1818. Fisher was appointed astronomer on HMS *Dorothea,* under the command of Captain David Buchan (1780-1838). The purpose of the voyage was to reach the North Pole via the polar sea. As astronomical observations were increasingly difficult in high latitudes, Fisher was instructed to be 'particularly attentive to ascertain the rate of your chronometers, as should you reach the Pole, your future course must mainly depend upon the accuracy with which you may be able to carry with you the time at Greenwich'.[79] Testing how the chronometers fared was not part of the instruction, although Fisher's experience with chronometers on this voyage led to his publication stating the detrimental effects of magnetism on chronometers. Unfortunately, an account of the chronometers was either not kept, or did not survive. In his report, Fisher references his observations made at Spitzbergen, where they compared the clock with nine chronometers (two Earnshaw's, four Arnolds, one Barraud, Baird and Pennington).[80] It is thus unclear exactly which chronometers were supplied to each voyage. Hurd's list of chronometers issued stated that in 1818 eight chronometers had been issued to Henry Browne's house; two to Captain Ross of HMS *Isabella*, and two to Captain Buchan of HMS *Dorothea.*

The issuing of chronometers and how they should be used was thus characterised by confusion and lack of regulations. As Waring put it, Sabine 'was unsure for whom exactly he

[79] Frederick William Beechey, *A Voyage of Discovery Towards the North Pole: Performed in His Majesty's Ships Dorothea and Trent Under the Command of Captain David Buchnan R. N., 1818; to which is added, a summary of all the early attempts to reach the Pole,* (London: Richard Bentley, 1843), p. 9

[80] George Fisher, 'On the Errors in Longitude as Determined by Chronometers at Sea, Arising from the Action of the Iron in the Ships upon the Chronometers', *Philosophical Transactions,* 110, (1820), pp. 198-208

was working' in publishing his experimental results related to his pendulum research.[81] This lack of a 'formal system of employment' and bureaucracy led individuals to turn to 'personal socio-economic networks'.[82] Such was the case of Henry Browne, not only a fervent supporter of science, but also very wealthy. Browne had made his fortune in the merchant navy and pursued astronomy in his retirement.[83] The basement of his house became the site in which naval officers were trained by Henry Kater in swinging the seconds pendulum, a crucial skill to determine length of the seconds pendulum at different latitudes and thus deduce the figure of the earth. Sabine, following a brief but successful military career, turned to astronomy, magnetism and ornithology in 1816, aided through his family connection to Browne (his brother-in-law). It was during this period that Sabine was introduced to Henry Kater, and in 1818, elected Fellow of the Royal Society. Immersed in this network of scientific gentlemen, Sabine was appointed to the Ross expedition as astronomer. Fisher, who conducted experiments at Spitzbergen to determine the length of the seconds pendulum, was also supplied with a pendulum that had been tested at Browne's basement. It was here that the Admiralty sent eight of the twelve government-owned chronometers that would accompany the 1818 Arctic expeditions. Browne's house boasted a transit circle and 'excellent time-pieces' (an Arnold pendulum clock and a 'time-piece by Cumming . . . considered by Mr. Browne to be the best in his possession'). The location was 'not liable to much disturbance from the passing of carriages' and had a stable temperature that could be raised if necessary.[84] Basil Hall was also part of this network. Hall commanded HMS *Conway*

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[81] Sophie Waring, 'The Board of Longitude and the Funding of Scientific Work: Negotiating Authority and Expertise in the Early Nineteenth Century', *Journal for Maritime Research*, 16, (2014), p. 59
[82] Waring, 'The Board of Longitude and the Funding of Scientific Work', p. 59
[83] *The Gentleman's Magazine and Historical Chronicle, from July to December, 1830*, Volume 2, (London: Printed by J. B. Nichols and Son, 1830), p. 541
[84] Henry Kater, 'An Account of Experiments for Determining the Length of the Pendulum Vibrating Seconds in the Latitude of London', *Philosophical Transactions of the Royal Society of London*, 108, (1818), pp. 40-41

between 1820 and 1823 and he conducted pendulum experiments in the Pacific and Atlantic, supported by Henry Foster. For this purpose, he also received training from Kater at Browne's place.[85]

The chronometers supplied to Parry were treated in the same way. With no official testing grounds, they were again sent to Browne's house in preparation for the expedition of 1819. Here, Sabine was able to determine a rate for each instrument over a period of five weeks. Most of the chronometers issued were made by Arnold and Earnshaw. Following a successful trial on the Ross expedition, the Admiralty purchased P&F 228 and issued it to the expedition. In addition to the seven government chronometers and two chronometers loaned by Browne, Parkinson and Frodsham loaned three instruments and the firm Finer & Nowland requested permission to send an instrument on board, requests accepted by the Admiralty. One of the chronometer's loaned by Parkinson and Frodsham, P&F 259, performed so well, that on return, Parry's officer bought the instrument for him (figure 3.4).

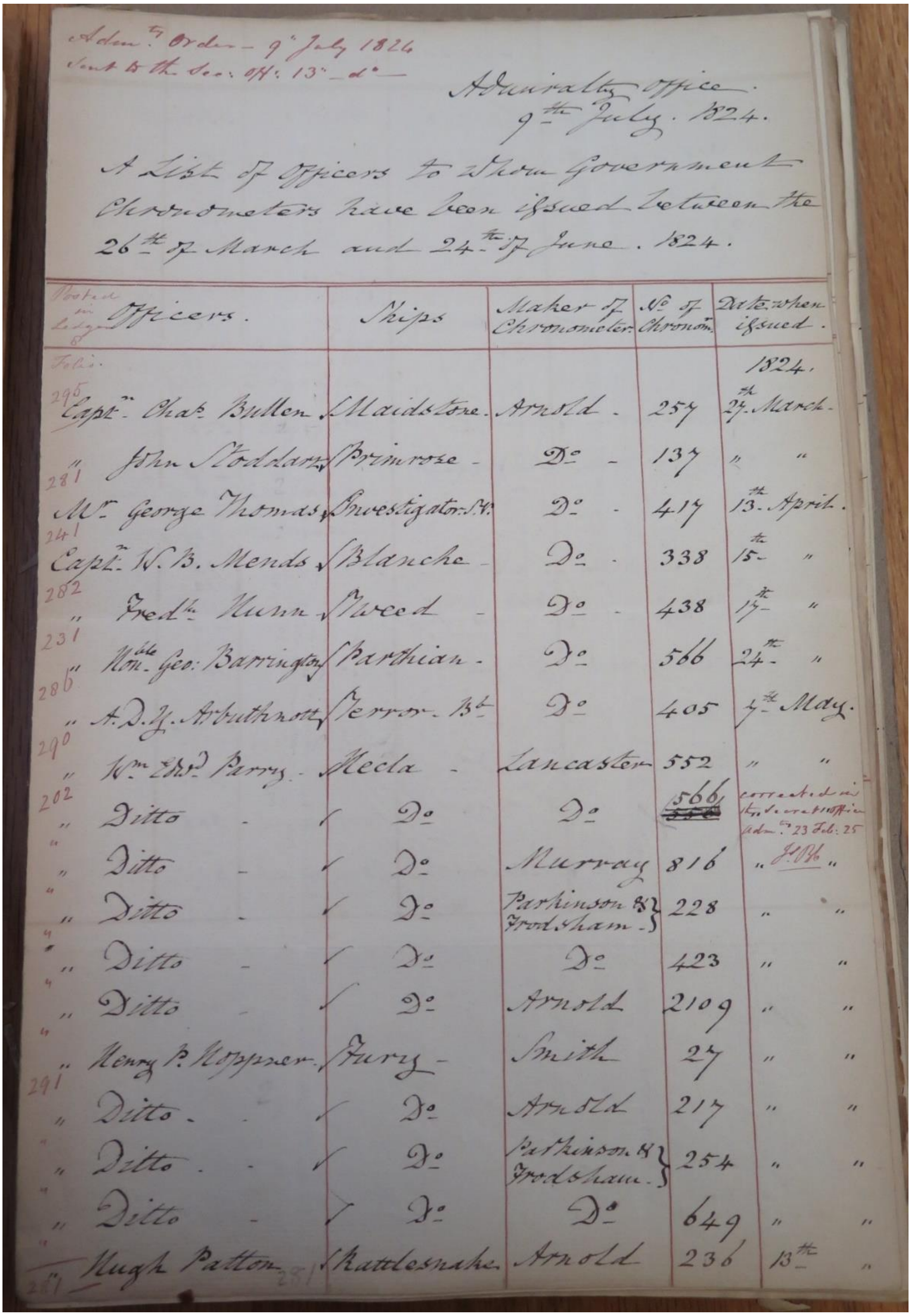
By the time Parry set out on his third voyage, in 1824, the situation had changed. Pond was now in charge of overseeing the chronometers and the Royal Observatory enabled the instruments to be rated by an astronomer before being sent out to sea. Parry initially wrote to Pond in January 1824: 'It being determined that another Polar Expedition should be undertaken, and it being of consequence that Chronometers which have already been tried in the Northern Regions should again be selected for that purpose, may I request you will allow the watches of Messrs. Parkinson & Frodsham in particular, which were returned from the Fury to be retained for our future use'.[86]

[85] Waring, *Thomas Young, the Board of Longitude, and the Age of Reform*, pp. 119-122
[86] William Parry to John Wilson Croker, 14 January, 1824. CUL, RGO 5/229, f. 155r

Figure 3.4: One-day box chronometer by Parkinson and Frodsham, no. 259. This chronometer was purchased for William Parry by his officers. (NMM ZAA0033). Betts, *Marine Chronometers at Greenwich*, pp. 280-281. © National Maritime Museum.

In January, Pond was 'indisposed' and his assistant Thomas Taylor dealt with the chronometer requests. This possibly explains why the correspondence concerning the expedition chronometers did not resume until March. Parry then wrote to Croker requesting instruments; four box chronometers and two pocket chronometers for the *Hecla,* the latter 'being found indispensable in making observations in a cold climate, which prevents the exposure of the other instruments'.[87] The next day, Barrow transmitted a copy of Parry's letter to Pond, requesting him to supply the ten chronometers to the expedition.[88] A list of the chronometers supplied to the *Hecla* and the *Fury* can be found in the archives of the Hydrographic Office (figure 3.5).

[87] Letter from William Parry to John Wilson Croker, Deptford, 15 March, 1824. TNA, ADM1/2358
[88] John Barrow to John Pond, Admiralty Office, 16 March, 1824. CUL, RGO 5/299, f. 167r



Adm.ty Order – 9th July 1824
Sent to the Sec: 14: 13 – d°

Admiralty Office.
9th July. 1824.

A List of Officers to whom Government Chronometers have been issued between the 26th of March and 24th of June. 1824.

Posted in Ledger Folio	Officers	Ships	Maker of Chronometer	No. of Chronom.	Date when issued.
					1824.
295	Captn. Chas. Bullen	Maidstone	Arnold	257	27th March
	" John Stoddart	Primrose	D°	137	" "
281	Mr. George Thomas	Investigator S.V.	D°	417	13th April
241	Captn. W. B. Mends	Blanche	D°	338	15th "
282	" Fredk. Hunn	Tweed	D°	438	17th "
231	" Honble. Geo: Barrington	Parthian	D°	566	24th "
286	" A. D. Y. Arbuthnott	Terror. Bt.	D°	405	7th May
290	" Wm. Edwd. Parry	Hecla	Lancaster	552	" "
202	" Ditto	D°	D°	566 ~~[illegible]~~	corrected in the Secret Office Adm.ty 23 Feb: 25
"	" Ditto	D°	Murray	816	" [illegible] "
"	" Ditto	D°	Parkinson & Frodsham	228	" "
"	" Ditto	D°	D°	423	" "
"	" Ditto	D°	Arnold	2109	" "
"	" Henry P. Hoppner	Fury	Smith	27	" "
291	" Ditto	D°	Arnold	217	" "
"	" Ditto	D°	Parkinson & Frodsham	254	" "
"	" Ditto	D°	D°	649	" "
281	Hugh Patton	Rattlesnake	Arnold	236	13th "

Figure 3.5: List of Government chronometers issued in 1824. UKHO, MLP82.

Parry received two chronometers from the maker Lancaster, two by Arnold, one by Murray, one by Smith and four from Parkinson & Frodsham. Pond supplied Parry with the same number of Parkinson & Frodsham chronometers as the previous voyage, although only two of those had been on that expedition. One of the Arnolds had also been supplied previously. These instruments had proved their reliability at sea, and were thus verified and valued by their users. As with previous voyages, the total number of chronometers exceeded those issued by the Admiralty. Parry and John Land Wynn (a lieutenant on board the *Hecla*) both carried their own private instruments and the firms Murray, Frodsham and Arnold each offered one chronometer for testing.

Foster and Fitzroy: chronometers for the measurement of meridian distances

Appointed to command the *Chanticleer* in 1828, Foster set out on 'an enterprise destined solely and simply for the promotion of scientific research, and the extension of the bounds of human knowledge'.[89] The voyage was a continuation of the pendulum experiments to 'establish the true figure of the earth and the law of the variation of gravity in different points of its surface'.[90] Foster had previously accompanied Basil Hall to South America in 1820 to assist in pendulum measurements and received the Copley Medal in 1827 for his pendulum experiments on Parry's third voyage. Foster was described by a midshipman on the *Fury*, as 'a distinguished navigator; he was an excellent officer, the best nautical scholar I ever knew, and a good astronomer'.[91] He was also a 'most intimate friend' of Captain Francis Beaufort (1774-1857) and enjoyed the support of Thomas Young, Secretary to the Board of

[89] Minutes RS committee, 28 January, 1828. RS, CM1
[90] Ibid
[91] An account of Parry's third voyage, probably written by Berkley Westrope, midshipman HMS Fury, Published in The Times (Halifax Nova Scotia) as follows, 17 March, 1835, 21 April, 1835, 6 October, 1835, photocopied typescript. SPRI, GB15: MS 1562;D

Longitude.[92] In collaboration with hydrographers from the Navy and the East India Company, the Royal Society selected fourteen pendulum stations that were critical for the expedition, but also beneficial for hydrography and navigation in general.[93] The Royal Society committee considered all other objects of the expedition secondary to the pendulum experiments. The chronometric objective of the expedition was varied. It was adopted primarily to connect points of longitudes determined astronomically at each of the pendulum stations to determine differences of longitude. By employing many chronometers, and by determining the time at principal ports and commercial stations, the committee hoped to judge the efficacy of the method and to approximately measure 'a great number of smaller intervals of high importance to navigation' without interfering with the primary aim.[94] For these determinations, the Admiralty ordered Pond to supply Foster with twelve of the best chronometers available.[95] Foster, like Parry, had a strong institutional network to rely upon.

Foster's chronometric orders were modelled on a previous voyage to Madeira orchestrated by the Board of Longitude and the Admiralty. Madeira was considered an important stop for sailors. In 1818, by orders of the Admiralty, Captain Bartholomew had received notice to 'ascertain that point, and that, generally, all HMS proceeding in the direction of Madeira, with time keepers on board, will have directions to attend to the same subject'.[96] By 1822, however, there was still no agreement on the matter, and Pond had determined that the longitude of Funchal was 5' in error. Following this, that same year, John Lewis Tiarks (1789-1837) was appointed as astronomer to a voyage in order solely to

[92] Adrian Webb, 'The Hydrographer, Science and International Relations: Captain Parry's Contribution to the Cruise of HMS *Chanticleer*', *The Mariners Mirror,* 96:1, (2010), p. 63; Waring, *Thomas Young, the Board of Longitude and the Age of Reform,* pp. 122-130

[93] The stations were: Para, Maranham, Fernando de Noronha, Ascension Island, Porto Bello, Trinidad, St Helena, Cape of Good Hope, Monte Video, Greenwich, Staten Island, Cape Horn, Deception Island, Port Bowen.

[94] Minutes RS committee, 28 January, 1828. RS, CM1

[95] Admiralty minutes, 7 February, 1828. TNA, ADM3/216

[96] John Barrow to Thomas Young, Admiralty Office, 24 November, 1818. CUL, RGO 14/49, f. 157r

determine the meridian distance between Falmouth and Madeira. In a letter to Young, Croker asserted that 'their Lordships . . . perfectly agree with the Board of longitude as to the expediency of ascertaining with the greatest possible accuracy the longitude of Funchal'. To facilitate the matter, they would 'furnish a proper vessel for this purpose' while the Board should 'point out the time, and have prepared the instruments & the instructions for the observers'.[97] This one-sided correspondence, from Croker to Young, reveals many of the uncertainties surrounding the issuing of chronometers, Pond's authority as superintendent, the relationship between the Board and the Admiralty and the accuracy of the methods to be employed.

Let me review the above three points. It is clear from the correspondence between Croker and Young that there was some confusion and disagreement over who should appoint a suitable astronomer, who should oversee the chronometers and how the expedition should proceed. Croker felt that 'the Board of Admiralty cannot give any opinion as to the person who may be fit to make the observations at Madeira. It will be the duty of the Board of Longitude to select a proper person for that purpose & to notify the same to the Admiralty' and that the 'Resident Committee should prepare the instructions for the person & should determine as to the number of chronometers &tc to be taken out & the mode of superintending them'.[98] Ten days later, Croker again wrote to Young asking him to act immediately, as 'the season [was] proper' and if he saw 'no prospect of getting a competent observer to undertake the observations a shore, not a moment should be lost in selecting ten or a dozen of the best going of the chronometers in order to their being immediately embarked in a frigate who should be directed to convey them to Madeira & back, departing from & returning to Falmouth'.[99] This appears to have resulted in a miscommunication

[97] John Wilson Croker to Thomas Young, Admiralty Office, 11 June, 1822. CUL, RGO 14/49, f. 161r
[98] Ibid, f. 164r
[99] John Wilson Croker to Thomas Young, Admiralty Office, 2 July, 1822. CUL, RGO 14/49, f. 167r

between the two, as Croker wrote again three days later asking 'when will the doctor & his instruments be ready to embark? I presume that you mean, tho' it is not clearly expressed, that the frigate & the chronometers should run out to Madeira, land the Doctor and return immediately to Falmouth & thence sail back to fetch the Doctor & the instruments. To save time I have written to the astronomer royal to select 6 8 or 10 of the best chronometers and to give their makers notice of the intended trial'.[100]

The Admiralty trusted the Resident Committee and the Astronomer Royal to select the appropriate observers for the celestial observations and for the care of the instruments. The Admiralty were able to organise the endeavour and select a suitable vessel. However, the letters reveal that Young believed chronometric measurement alone would be sufficient, whilst it was the Admiralty's intention that the method should be tested against astronomical observations in order to test the efficiency of chronometric differences. Croker made this very clear the following day, when he again corresponded with Young:

> Of course we must be satisfied with what shall be thought satisfactory by the Board of Longitude, but it occurs to us that the observations on shore should be made with great care, nicety, & deliberation & although it may be expected that the chronometers will give a nearer approximation to the truth, than the observations, this must be mere expectation & one advantage of the experiment will be the bringing careful observations to bear upon the best chronometrical calculations. It seems therefore that the observations by Dr Tiarks should be made in the most compete & scientific manner, else, they had better, for all our sakes, not be made at all.[101]

The Admiralty wanted two determinations of longitude, one on shore by observations, the other by 'chronometers afloat'.[102] Tiarks was to be the on-shore observer, and a second person, selected by Pond and the Resident Committee, was to have care of the chronometers. Croker had made clear in conversation with Young that he wished 'to keep

[100] John Wilson Croker to Thomas Young, Admiralty Office, 5 July, 1822. CUL, RGO 14/49, f. 169r
[101] John Wilson Croker to Thomas Young, Admiralty Office, 6 July, 1822. CUL, RGO 14/49, ff. 171r-171v
[102] John Wilson Croker to Thomas Young, Admiralty Office, 8 July, 1822. CUL, RGO 14/49, f. 173r

the result of the chronometer time a secret from the observer'.[103] In addition, Young believed that one trip to Funchal should be sufficient, whilst Croker wanted the chronometers to take two trips. Young also proposed that 'little stress is to be laid on the observations & a great deal on the chronometers', leading Croker to reply that this would 'diminish the chronometer experiment by one half without at all improving the other'.[104] Croker then requested Young and Tiarks to call on him to discuss the matter. Judging by the manner in which the voyage preceded, it seemed that Young was able to convince the Admiralty that the method of chronometric distances would be sufficient for the purpose. Tiarks subsequently sailed to Madeira and back between the 24 July and 29 August 1822, with his chronometers. At Falmouth and Madeira, he determined the rates of the chronometers by Equal Altitudes of the Sun. No other astronomical observations were made.

Pond meanwhile was ordered to 'select a sufficient number of the best going chronometers'.[105] Even though he was trusted with selecting these instruments, Pond was seen to overstep his authority by authorising an additional four instruments (likely instruments leant for trial by their makers) to the total of twelve issued by Admiralty order. Their Lordships disapproved of the other instruments and ordered 'Captain Spencer & Dr Tiarks not to take any account of their rates of going'.[106] Pond convinced the Admiralty of his reasons for supplying these additional instruments, who then permitted 'all the chronometers to proceed, tho' there are some points which they do not yet perfectly understand & could have wished that the Private Watches had not been sent'.[107] Considering that with chronometric differences, in general it was perceived that a greater number of instruments was better, it is surprising that the Admiralty were so opposed to the addition

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[103] John Wilson Croker to Thomas Young, Admiralty Office, 8 July, 1822. CUL, RGO 14/49, f. 174r
[104] Ibid, f. 174v
[105] Minute of the Board of Admiralty, 6 July, 1822. TNA, ADM12/210
[106] Admiralty Digest, 1822. TNA, ADM 12/210, tab 98a Mathematical Instruments
[107] Ibid

of these instruments. As the trials were intended for public benefit, they may have feared this would lead to a loss of trust in the trials. What is clear is that the Admiralty had to approve each chronometer added to the voyage.

Pond reported back to the Admiralty on the return of the voyage. He found that the 'discordances [were] not greater than I expected from previous experiments and I have little doubt but that the difference of longitude of these two places is now as correctly known as that of Greenwich and the principal observatories in Europe'. He added that even if 'future revision may improve this result a very small quantity' the 'performance of the chronometers will remain exactly the same'. 'Upon the whole', Pond was 'persuaded the experiment has been as successful as it was important'.[108] Tiarks' voyage convinced Pond of the success of chronometric distances, and Pond in his turn convinced the Admiralty, yet caution in the method and its results remained evident throughout the following decades. Consequently, the Admiralty ordered similar experiments to be performed upon a variety of Royal Navy expeditions, notably including the voyages of HMS *Adventure,* under command of Captain King (1826-1830); HMS *Chanticleer,* under Captain Foster (1828-1831); and HMS *Beagle*, under Captain Fitzroy (1831-1836). All three expeditions sailed with a large number of chronometers in order to measure meridian distances in the same manner as Tiarks had done before them.

Issuing chronometers to Foster and Fitzroy was far more straightforward. After six years of chronometer trials at Greenwich, Pond had a greater number of instruments to choose from (though he still had to purchase additional instruments to make up the numbers). The use of a large number of 'the best' chronometers to measure meridian distances became accepted as a method, although astronomical observations were still seen as the only method to truly establish a longitude. A meeting of the committee was held on

[108] John Pond to the Admiralty, 11 September, 1822. TNA, ADM 1/3462

28 January 1828 to determine the aims of Foster's voyage. Present were Davies Gilbert (President to the Royal Society), Francis Beaufort (at this point still a captain in the Royal Navy), William Henry Fitton (President of the Geological Society), John Herschel (President of the Astronomical Society), Captain Kater, Peter Mark Roget (Secretary of the Royal Society) and Captain Sabine. Parry (then Hydrographer to the Navy), Foster and James Horsburgh (Hydrographer to the East India Company) attended by invitation.[109] The point of the chronometric measurements was solely to connect the longitudes determined astronomically at the pendulum stations and extended the experiment initiated with Tiarks in 1822, as the following extract underlines:

> The committee are far from considering that great intervals of longitude thus obtained even by the mean of a great number of chronometers can be compared in point of accuracy with those resulting from direct independent determinations from astronomical observations such as eclipses, occultation's and the lunar methods. But they conceive that by the employment of 12, 18 or any greater number of their instruments of good and ascertained character which can be placed at Captain Foster's disposal not only may be satisfactory estimate be found of the actual efficacy of the method of chronometers, by checking their results in trips of various lengths with those already well known, or determined by better means in the course of the expedition but also that a great number of smaller intervals of high importance to navigation may thus be ascertained with a great degree of approximation, which the other objects of the expedition would not allow of being determined independently.[110]

Although issuing chronometers was delegated to Pond, the Admiralty remained in control. In December 1828, Foster requested a list of instruments he required for the voyage from Young. The list covered two pages, specifying thirty-seven different instruments; most of these were for astronomical purposes, but they also included instruments for magnetic, meteorological and observational research. Written in the margin in pencil, either by Young or an unknown Admiralty hand, is specified who owned the instruments required, in most cases this was the Admiralty or the Board of Longitude. At the top of the list, Foster requested

[109] Minutes of a Meeting of the Royal Society, 28 January, 1828. RS, CM/1
[110] Ibid

thirty chronometers. The chronometers were listed as Admiralty property, and in pencil the amount was adjusted to ‘12’ with the additional remark ‘or as many as possible’ (figure 3.6).[111]

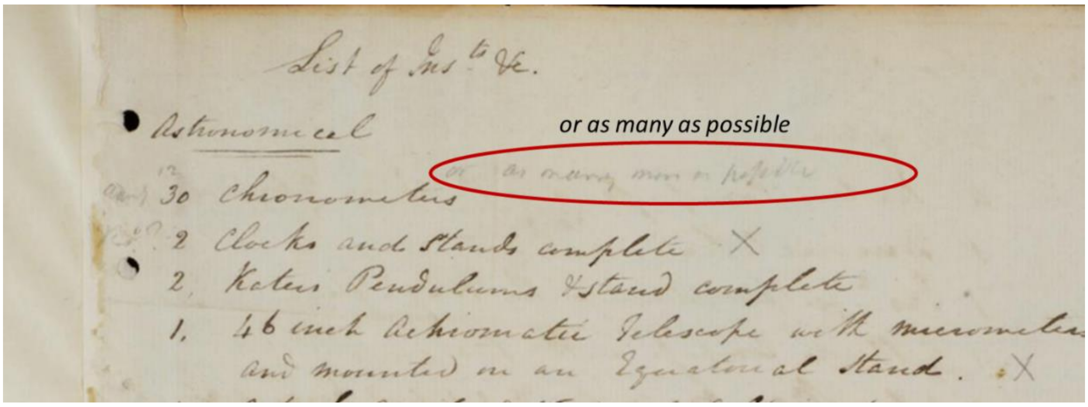

Figure 3.6: List of instruments requested for HMS *Chanticleer*. CUL, RGO 14/49, f. 60r

Before the *Chanticleer* departed, Foster requested that the chronometers (‘not less than eighteen’) should ‘for a considerable time previous to their embarkation, be in the hands of the Astronomer Royal, for the purpose of determining their rates’.[112] Pond was then directed by Barrow to have ‘twelve chronometers of the best qualities prepared’.[113] Ultimately, the *Chanticleer* sailed with fifteen chronometers: two on loan from the makers, one belonged to Foster, all others were government-owned (figure 3.7).

[111] Henry Foster to Thomas Young, December, 1828. CUL, RGO 14/49, f. 60r
[112] Henry Foster to John Wilson Croker, Athenaum, 15 January, 1828. TNA, ADM1/1816
[113] John Barrow to John Pond, Admiralty Office, 7 February, 1828. CUL, RGO 5/230

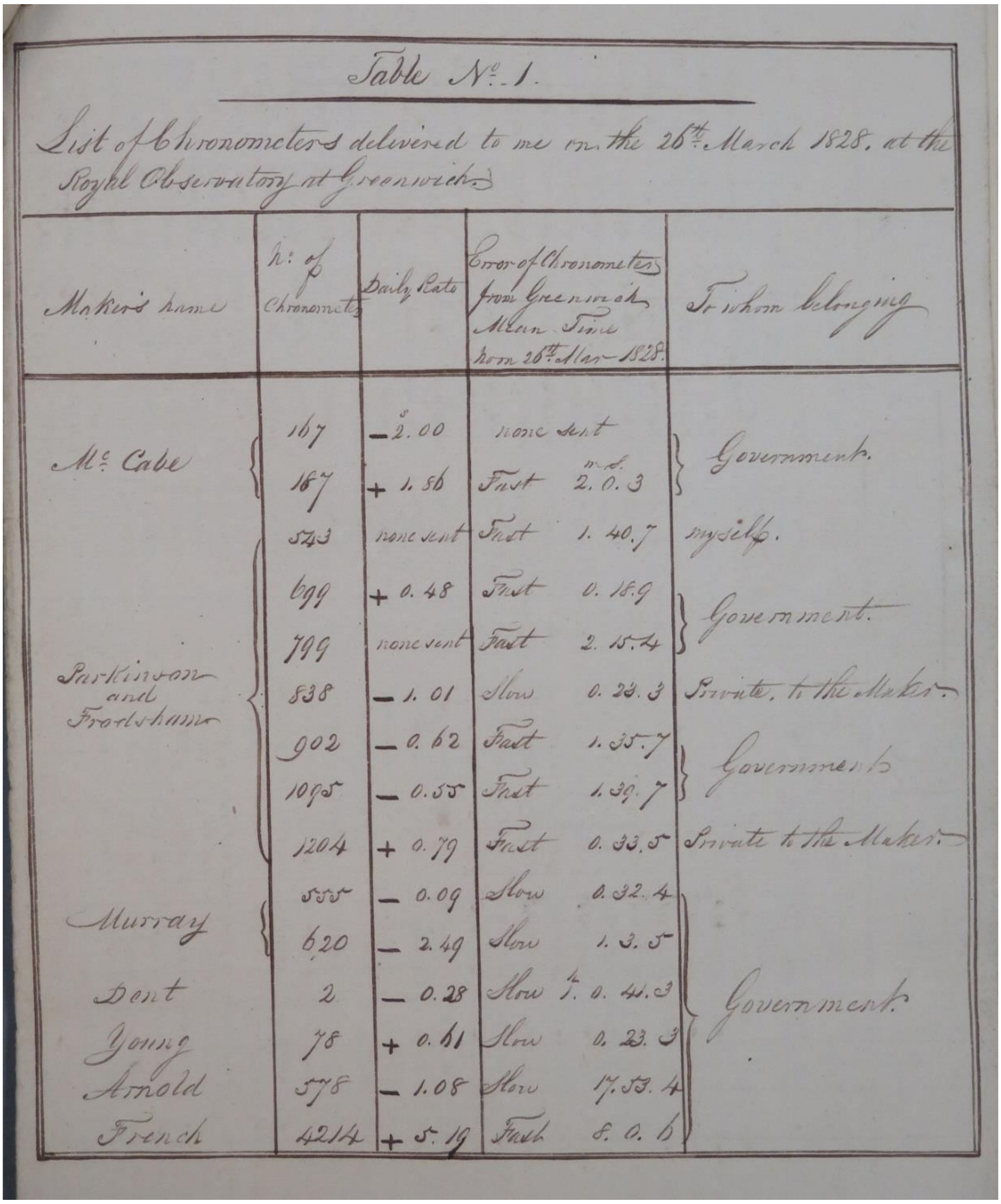

Table No. 1.

List of Chronometers delivered to me on the 26th March 1828, at the Royal Observatory at Greenwich.

Maker's name	No. of Chronometer	Daily Rate	Error of Chronometer from Greenwich Mean Time noon 26th Mar 1828.	To whom belonging
Mc Cabe	167	− 2.00	none sent	Government.
	187	+ 1.56	Fast 2. 0. 3	
Parkinson and Frodsham	543	none sent	Fast 1. 40. 7	myself.
	699	+ 0.48	Fast 0. 18. 9	Government.
	799	none sent	Fast 2. 15. 4	
	838	− 1.01	Slow 0. 23. 3	Private, to the Maker.
	902	− 0.62	Fast 1. 35. 7	Government
	1095	− 0.55	Fast 1. 39. 7	
	1204	+ 0.79	Fast 0. 33. 5	Private to the Maker.
Murray	555	− 0.09	Slow 0. 32. 4	Government.
	620	− 2.49	Slow 1. 3. 5	
Dent	2	− 0.28	Slow 1. 0. 41. 3	
Young	78	+ 0.61	Slow 0. 23. 3	
Arnold	578	− 1.08	Slow 17. 53. 4	
French	4214	+ 5.19	Fast 8. 0. 6	

Figure 3.7: List of Chronometers supplied to HMS *Chanticleer.* UKHO, AO32: SFD7/7/1/7

Fitzroy was aided by Beaufort and a 'kind uncle' for his expedition on HMS *Beagle.*[114] Fitzroy, having served on the first voyage of the *Beagle* (he took over her command after Captain Pringle Stokes committed suicide), had been under the impression that another voyage would be ordered to continue the survey. The Admiralty initially opposed this but

[114] Robert Fitzroy, *Narrative of the Surveying Voyages of His Majesty's Ships* Adventure *and* Beagle *between the years 1826 and 1836*, Volume II, (London: Henry Colburn, 1839), p. 13

Fitzroy's uncle intervened; he 'went to the Admiralty, and soon afterwards told me that I should be appointed to the command of the Chanticleer, to go to Tierra de Fuego'.[115] Fitzroy did not identify which uncle, and he had many: his family was an old aristocratic one with influential connections. His father, Lord Charles Fitzroy, was an army officer and politician, and his grandfather, Augustus Henry Fitzroy, was the third Duke of Grafton and Prime Minister between 1768 and 1770. Beaufort was also supportive of the endeavour and was instrumental in setting-up the instructions for the voyage. It was Beaufort who requested specific chronometers from Pond: Earnshaw 705, Frodsham 1, Arnold 465 and Parkinson 1048.[116] The Admiralty offered Frodsham £100 for Frodsham no. 2 after it performed well at trial. They accepted the offer and requested the Admiralty to also consider purchasing no. 1, although it had performed less well. According to Frodsham, this was down to the temperature adjustment, which they had improved. Beaufort, rather than Pond, recommended purchasing the instrument, as it was 'good' for 70 guineas, based on its trial number and the pay scale adopted.[117] The chronometers selected for these voyages remained out of bounds to other users. The *Beagle* did not leave Devonport until 27 December 1831. In July 1831, a captain requested the use of a chronometer reserved for the *Beagle,* as he was to set out immediately. The request was refused.[118] Access to these instruments, then, considered to be the best by the Observatory standards, was dependent on the social and institutional networks in which one operated.

[115] Fitzroy, *Narrative of the Surveying Voyages, Volume II*, p. 13.
[116] Francis Beaufort to John Pond, Admiralty Office, 8 July, 1831. CUL, RGO5/231, f. 43r
[117] Francis Beaufort, 20 January, 1831. TNA, ADM 1/4609
[118] Admiralty Digest, Mathematical Instruments, 1831. TNA, ADM12/278

Owen: hydrographic surveying on the East African Coast

Scientific or exploration voyages were thus held in high esteem, and were issued with the best chronometers that Pond had on offer. In 1829, Pond even discouraged the purchase of the chronometers on trial, as 'should no particular scientific expedition be in contemplation by their lordships, I do not on my part see any urgency for their purchase'.[119] Surveyors enjoyed no such standing. Croker saw the Hydrographic Office 'as a wasteful expense and surveying as unnecessary diversion'.[120] Entrance to the service had even been described as 'an act of "self-immolation"' in terms of an officer's opportunities for promotion and career prospects.[121] Surveyors could not necessarily draw on the same resources as naval officers such as Parry, Foster and Fitzroy did. As with Fitzroy, where they could, it was because of the social standing they had, rather than from their employment as surveyors. Admiralty-sponsored expeditions were still clearly a higher priority. Even so, and to judge from the chronometers issued during the first quarter of the nineteenth century, surveyors were still important figures and their standing increased with the expansion of the Hydrographic Office under Thomas Hurd, William Parry and Francis Beaufort.[122]

The captains of HMS *Leven* and HMS *Barracouta*, William Fitzwilliam Owen and William Cutfield respectively, wrote to the Admiralty requesting chronometers. Croker forwarded the application to Pond on their behalf. For the two vessels, nine chronometers in total were issued from the Observatory in 1821: five to HMS *Leven,* four to HMS *Barracouta.* Owen requested that he 'be supplied with two of the <u>condemned</u> chronometers now in store, in

119 John Pond to John Wilson Croker, Royal Observatory, 25 August, 1829. TNA, ADM1/3470

120 Megan Barford, *Naval Hydrography, Charismatic Bureaucracy, and the British Military State, c. 1825-1855*, Unpublished PhD, University of Cambridge, (2016), p. 3

121 Barford, *Naval Hydrography, Charismatic Bureaucracy, and the British Military State*, p. 3

122 Megan Barford, 'D.176: Sextants, numbers, and the Hydrographic Office of the Admiralty', *History of Science*, 55, (2017), pp. 431-456; Webb, 'More than just Charts: Hydrographic Expertise within the Admiralty, 1795-1829', pp. 43-54; Webb, *The Expansion of British Naval Hydrographic Administration*, pp. 300-310

addition to the Chronometers now on charge, to enable him to carry time from place to place in the Boats or otherwise, without disturbing the latter from their places'.[123] From these requests, it is clear that Owen was of the opinion that moving chronometers around would be detrimental to their use. Like the polar voyages, the chronometers issued by the Admiralty were not the only ones used during the five years of surveying. Unfortunately, despite the comprehensive 'Essay on Chronometers' written by Lieutenant Richard Owen of HMS *Leven*, Owen did not specify which particular instruments were used. This could be because his 'Essay' was intended as a general instruction, on how to manage chronometers, but it could also indicate that Owen viewed the instruments as (almost) interchangeable. Figure 3.8 shows the chronometers that were used on board HMS *Leven* and HMS *Barracouta* during the survey.[124]

[123] John Barrow to John Pond, 11 October, 1821. CUL, RGO 5/229, f. 11r

[124] The Table is comprised based on the following sources: Richard Owen, *Essay on Chronometers*, (London: Printed by Duckworth and Ireland, for the Hydrographical Office, 1827); 'List of government chronometers'. UKHO, MLP 82; Barrow to Pond: 'List of instruments on board HMS Leven belonging to His Majesty. Originally supplied from the Hydrographical department of the Admiralty Office'. CUL, RGO5/229, f. 361r;

HMS Leven

Maker & no.	Type	Issued	Owner
Arnold 498	8-day box	1821 London	Government
Arnold 503	Box	1821 London	Government
Arnold 1970	Pocket	1821 London	Government
Young 6303	Hack watch	1821 London	Government
Margetts 97	Hack watch	1821 London	Government
Arnold 1870	Pocket	1822 Cape of Good Hope	Purchased by Owen, lost in Zambezi
Barraud 618	Box	1823 Bombay	Purchased by Owen, reimbursed on return
Arnold 323	Box	1825 London	Government
Arnold 1891	Box	1822 Cape of Good Hope	Purchased by Owen, reimbursed on return
French 1809	?	1822 Cape of Good Hope	Purchased by Owen, reimbursed on return
Brockbanks & Atkins 3454	?		Owen
HMS Barracouta			
Margetts 223	?	1821 London	Government
Margetts 163	?	1821 London	Government
Barraud 10	Box	1821 London	Government
Barraud 517	?	1821 London	Government
French 1640	Box	Unclear	Government
Massey	?		Owen

Figure 3.8: Table containing the chronometers used by the *Leven* and *Barracouta* during the East African Survey.

Due to this lack of specification, it is unclear exactly how many chronometers were used on the voyage. Parry had requested particular instruments because of his experience with them in particular conditions. William Fitzwilliam Owen's faith lay more in the method, which indicates that the status of the instrument was less important, as the method would justify the results, not the status of the instrument. As Owen did not have access to several 'good' instruments, he relied on strict methods of use to guarantee their reliability. Owen employed a stricter hierarchy of instruments than the other users considered in this thesis. Of the five chronometers issued to the *Leven*, two were considered hack watches (the condemned chronometers cited above), which Owen used to compare time between instruments. A pocket chronometer was issued, but Owen did not specify what this particular instrument was used for. The remaining two box chronometers, considered the best, were used as the standards (Arnold 498 and Arnold 503). Owen did not have much success with his chronometers. By 1823, 'all our chronometers had failed, except one; that had also fluctuated in rate, so we could not depend on the meridian distance shewn by any of them'.[125]

Owen's problems with the instruments reveal the complications that chronometer users still needed to overcome. To deal with them, Owen purchased additional instruments at his own expense. These included two pocket watches at the Cape of Good Hope in September, 1823 and one box chronometer in Bombay, in December 1823. On return to England, Owen was reimbursed for the costs and the chronometers became government property. One pocket chronometer was bought by Owen in 1822 (an Arnold 1870) but this was lost during the survey of the Zambezi, along with Lieutenant Browne and his men.[126] Whilst Owen purchased chronometers abroad, to replace those that malfunctioned, he only replaced the pocket and hack chronometers. When it came to the chronometers that Owen kept below decks, those used as standards, Owen applied to the Admiralty to supply these from England.

[125] Owen, 'Tables of Latitude and Longitude', p. 13
[126] Stuart Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey', *Antiquarian Horology,* 40:2, (2019), p. 207

Figure 3.9: One-day box chronometer by John Roger Arnold, no. 323. Issued to William Owen from the Royal Observatory, 1825. (NMM ZAA0117). Betts, *Marine Chronometers at Greenwich*, pp. 261-263. © National Maritime Museum.

There was, in other words, a clear hierarchy here; chronometers to be used as the standard required the authority of appropriate individuals such as Pond to determine their status. In 1825, Owen received Arnold 323 (figure 3.9) as a replacement chronometer for Arnold 503, which he had sent back to England for repair.[127] In addition to these instruments issued, purchased and exchanged. Owen also carried his own chronometers. On requesting

[127] Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey', p. 209

that the Admiralty pay the bill for the repair of his own chronometer Brockbanks and Atkins 3454 (which they refused), Owen mentioned that he 'embarked several chronometers belonging to myself to aid me in the observations required'.[128] A final chronometer listed by Jennings is French 1640, but it is unclear where this instrument was purchased and by whom. It was used on the tender *Albatross*, and Richard Owen also mentioned it in his 'Essay on Chronometers'.

Conclusion

Pond wrote in 1829 that the 'chronometers in question are much superior to those of former years, indeed the rates of improvement in the last few years may be I think fairly stated as at least two to one'.[129] The Premium Trials had at least succeeded in their aim of improving the performance of chronometers on shore. While the rating of chronometers remained under the supervision of the Observatory, Pond's management of chronometer issue was short-lived. Hurd would have been pleased that the responsibility returned to the Hydrographer in 1829, under the supervision of Beaufort. A growing stock of chronometers at Greenwich meant that increasing numbers of Royal Navy ships could be issued with them. The addition of the marine chronometer to the navigational equipment meant that ships could potentially sail more quickly and with increased certainty. Until the 1820s, chronometers had not yet had a great effect on the practices of navigation; traditional methods were still adhered to by the captain or master navigating the ship. Transforming practice at sea required more than just the addition of another piece of hardware, especially one that was liable to uncertainty and error. Yet specific groups of users saw the benefit that could be achieved if

[128] William Fitzwilliam Owen to John Wilson Croker, HMS *Eden*, Woolwich 26 May, 1827. TNA, ADM 1/2272

[129] Copy of a letter to John Wilson Croker, Royal Observatory, August, 1829. CUL, RGO 5/233, f. 49r

standardised practices were adhered to. The Hydrographic Office in particular was keen to promote this and played a central role in chronometric matters.

On land, the business of chronometry had changed. The market had opened up to chronometer makers. Official trials were initiated on which the merits of individual instruments could be judged. The Admiralty, with assistance from the Hydrographer and the Astronomer Royal, took control of government stock and supply and, more importantly, had the authority to judge the merits of individual chronometers. As a result, 'the systems of the state, not the trade . . . gave their timekeepers value'.[130] Thus at Greenwich, the Astronomer Royal became an authority on chronometers.

This chapter has also shown that what had proved possible on land required replicating at sea. Observatory Staff, with the help of the university-based mathematicians, were now trained in the use of observing instruments and regulators, and they selected the instruments that performed best in the (relatively) stable environment of terrestrial sites. At sea, most users found that the rates of the instruments altered, although they did not agree upon the cause. How an individual evaluated the reliability depended entirely on what they believed caused irregularities in their chronometers. Parry and Sabine considered their chronometers, which had been specifically adjusted for the cold climate of the Arctic, reliable. Fisher on the other hand, was suspicious of their performance as he believed magnetism would have a detrimental effect on their rates.

Astronomical observations went hand in hand with chronometric measurements. By the 1820s, the Admiralty was still not convinced of the accuracy of chronometers and wished to test them against astronomical observations made on shore. As is clear from the correspondence concerning the method for best determining the longitude of Funchal in Madeira, opinions varied as to what the most accurate method might be. Owen had to make

[130] Phillips, *Making Time Fit*, p. 65

similar judgements, although rather than between methods, Owen determined strict hierarchies between his instruments. He clearly considered chronometers unstable, and cautioned others not to become too reliant on them. To counter this inherent problem, Owen advised strict procedures for their use. From these examples it is clear that one's social network had a direct outcome on chronometric practice. Parry, Foster and Fitzroy, all well-connected gentlemen charged with the command of prestigious expeditions were allocated the best resources on offer. The Arctic voyages in particular had the support of John Barrow. William Fitzwilliam Owen, as only a surveyor, lacked the standing of his fellow naval officers employed on these scientific expeditions and had to make do with 'lesser' instruments.[131]

Determining the rate of the instrument was the most important but also the most challenging aspect of practice. Because an observatory regulated clock was not available at sea, navigators turned to traditional celestial observations to determine the changes taking place in their instruments. Introducing new technologies required guidance and instructions on how best to implement them. Instructions for chronometers came from a variety of sources: textual instruction, on-board learning, and experimental experience. Hurd, and later Parry and Beaufort, each promoted hydrography and collected significant amounts of data at the Hydrographic Office. They saw the potential, through disciplined instruction, that the collection of chronometric data had for increasing the reliability of Admiralty charts. The next chapter examines how users were instructed in the use of the instruments and what this meant for the practices they implemented.

[131] Webb, 'More than just Charts: Hydrographic Expertise within the Admiralty, 1795-1829', p. 46; Barford, *Naval Hydrography, Charismatic Bureaucracy, and the British Military State,* p. 3

4

Naval Education and Chronometric Instruction

> But this can never be strictly true unless she be not only provided with a chronometer, but with officers familiarised to the use of this instrument. Let an officer's theoretical knowledge be what it may, he will perform his voyage, whether short or long – in a manner much inferior to that of another officer who, without his zeal, knowledge, or talents, had by some accident rendered himself practically master of this important branch of his duty.[1]

Introduction

When the chronometer was introduced at sea in the 1770s, instructions about how to use them in navigational manuals were limited to a short description of this 'mechanical solution', which was considered too expensive and too unreliable for general use at sea.[2] This scant description did not change until the early nineteenth century and even then, remained limited. Not until the 1820s and 1830s did more in-depth instructions become available, either as instructions distributed to Royal Navy captains, as a section in a navigation manual, or as a separate publication. In 1855, Captain Charles Shadwell (1814-1886) published a 158-page instruction manual on the management and use of chronometers.[3] Much had changed concerning chronometer use at sea in the intervening years: it is also clear, as this chapter shows, that most of these developments had occurred as experimental practices on board ship.

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[1] Basil Hall to Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956.
[2] John Robertson, *The Elements of Navigation; Containing the Theory and Practice, Volume II,* (London: Printed for J. Nourse, 1772), Book IX, p. 341
[3] Charles F. A. Shadwell, *Notes on the Management of Chronometers and the Measurement of Meridian Distances*, (London: J. D. Potter, 1855)

Understanding these early experimental practices is challenging given the scarcity of records. Research into the uptake and early use of these methods has focused predominantly on two sources: logbooks and navigational manuals. Interpretations of the logbooks indicate that the Royal Navy was slow to take up chronometers, particularly in comparison with the East India Company which, in 1791, introduced an additional column into their logbooks for the longitude by chronometer.[4] May has shown that most of the chronometers in circulation were used either privately, by captains of the East India Company, or on Royal Navy exploration or surveying expeditions.[5] Most of these instruments were supplied by a few makers, the majority from Arnold, as noted in the previous chapter. May's research indicated a lack of chronometric instruction and Wess has similarly noted the sparsity of lunar instruction in navigational manuals from the late eighteenth century.[6] Wess also noted a lack of 'longitude by lunar' in late eighteenth-century East India Company logbooks. From the examination of logbooks and navigation manuals, Wess concluded that within the East India Company, the lunar distance method was only used on exploration voyages and 'just as likely a chronometer would be preferred, or neither'.[7]

Study of the logbooks of the East India Company has revealed a different picture. Davidson examined 587 East India Company logbooks for the period 1770-1792. In total, 45% of these voyages used lunar distances and 22% used chronometers. Within this period, chronometer use increased towards the end of the century whilst records of the lunar distance method started to decline. The method of dead reckoning was also taken into

[4] William E. May, 'How the Chronometer Went to Sea', *Antiquarian Horology*, 9, (1976), pp. 638-663; Simon C. Davidson, Marine Chronometers: The Rapid Adoption of New Technology by East India Captains in the Period 1772-1792 on over 580 Voyages', *Antiquarian Horology*, Vol. 40, (2019), pp. 76-91.
[5] May, 'How the Chronometer went to Sea', pp. 638-663
[6] May, 'How the Chronometer went to Sea'; Jane Wess, 'Navigation and Mathematics: A Match Made in the Heavens?', in: *Navigational Enterprises in Europe and its Empires, 1730-1850,* Richard Dunn and Rebekah Higgitt, eds. (Basingstoke: Palgrave Macmillan 2016), p. 208
[7] Wess, 'Navigation and Mathematics', p. 215

account in this study, but only when it was used as the sole method for determining longitude.[8] This study showed that by the 1790s, dead reckoning was always supported by either chronometers or lunar observations. But it must not be forgotten that dead reckoning underpinned all navigation, and without it, a ship simply could not sail.

These studies show that different pictures emerge depending on the nature of the source material examined. Lack of lunar instruction in navigational manuals does not necessarily preclude chronometers' use at sea. The use of lunars on both Royal Navy and East India Company ships reveals that not all users were reliant on these manuals to learn new methods. This raises the question of who was the intended audience for these manuals and if the early users of these methods were part of that audience. The same trend can be seen in chronometry. Davidson's study showed that chronometer use in the East India Company increased from only 4% in the 1770s, to 82% by 1791-92, based on the evidence from the logbooks studied.[9] At that time, however, published chronometric instruction in navigational manuals was still almost non-existent, as May has pointed out and as this study also supports. These source materials are thus problematic and interpretations from them should be made with caution; but this does not mean they are without merit. Secord challenges us to think about 'every text, image, action, and object as the trace of an act of communication, with receivers, producers, and modes and conventions of transmission'.[10] We can see from these studies by May, Wess, and Davidson that textual instruction in navigation manuals did not reflect actual use at sea, and that practice at sea developed more rapidly than the instruction in books. Studying the interaction of both instruction in print and practice in the field can give a richer view of the development of practice, to see 'knowledge not just as abstract doctrine

[8] Davidson 'Marine chronometers: The Rapid Adoption of New Technology by East India Captains', pp. 638-663

[9] The percentages are based on the number of voyages carrying chronometers in a particular year.

[10] James A. Secord, 'Knowledge in Transit', *Isis*, 95, (2004), p. 661

but as communicative practice in a range of well-integrated and closely understood settings'.[11]

The fact that users had to turn to other sources to learn the technologies suggests that in these early stages, users are key to understanding how these manuals related to practice at sea. Context is also important. Given that navigation was an established practice, and manuals had been in circulation since the sixteenth century, the question why instruction in these new methods remained relatively absent is a crucial one. For methods so desperately needed, the lack of instruction contrasts sharply with the research and rewards being devoted to these so-called longitude solutions.[12] Yet, two publications circulating in the late eighteenth century deserve specific attention: the first is Alexander Dalrymple's *Notes on Chronometers*, published in various forms between 1786 and 1788. The second is William Wales' *Method for Finding the Longitude at Sea,* published in 1794. Both works deserve our attention for two reasons: they highlight the basic skills and knowledge necessary for the use of chronometers, and they demonstrate that because the aims of various users differed, so did the emphasis as to what was the subject of instruction. Therefore, if we compare how the chronometers were used in the various case studies, we also see differences in what was expected of the instrument. Although the case studies studied below were using chronometers between 1819 and 1836, most of the captains were introduced to navigational practices during the end of the eighteenth century and in the first two decades of the nineteenth century.

This chapter is divided into two main sections. The first examines chronometric instruction in general navigation manuals between 1770 and 1820, and the context in which they were used. This cut-off point reflects the end of the Napoleonic Wars and the effect this

[11] Secord, 'Knowledge in Transit', p. 671
[12] May, 'How the Chronometer went to Sea'; Wess, 'Navigation and Mathematics: A Match Made in the Heavens?'

had on naval education and on the careers and status of naval officers, and, more directly, because most of the officers within these case studies went to sea within this period. This section also examines the role that shore-based education played in the training of a naval officer. The question of different schooling is, I argue, key to understanding how we interpret these textual instructions which must be placed within the broader context of a naval education. The two works by Dalrymple and Wales identified above are examined in relation to the users they were intended for and for what they reveal about the authors' perceptions of problems that would be encountered in the use of chronometers.

The second section examines the change in naval culture following the end of the Napoleonic Wars and the emergence of what has been termed 'the scientific naval officer'.[13] New cultures within the Admiralty influenced the careers of officers after 1815 and the aims of the Navy changed significantly in the transition from war to peace. Peace time operations increasingly focused on scientific pursuits at sea. These are reflected in Parry's Arctic voyages, Owen's survey, Foster's scientific expedition and Fitzroy's chronometric expedition. Following the points made in the preceding chapter, I examine these voyages in terms of their captains, to evaluate their naval training and education in the context of this 'navy in transition' and their social standing and connections within the Admiralty and the scientific societies.

On shore: naval education and textual instruction

As chronometers were developed to assist navigators in determining their longitude at sea, one might expect that the explanation of their use would be disseminated through the navigational manuals that were prolific in the late eighteenth and early nineteenth centuries.

[13] Randolph Cock, 'Scientific Servicemen in the Royal Navy and the Professionalisation of Science, 1816-55', *Science and Beliefs: From Natural Philosophy to Natural Science*, *1700-1900,* Matthew D. Eddy, ed. (London: Routledge, 2005), pp. 95–112

These manuals built on a tradition dating back to the sixteenth century but had, over time, developed into hefty volumes, often written from a theoretical perspective by authors who did not practice navigation at sea. The manuals would instruct seamen on plane- and great circle sailing, navigational instruments (cross-staff, compass, astrolabe, sea charts), the motions of the Moon and tides and the rules for meridian altitudes for finding latitude. As practices developed throughout the seventeenth century, new instruments, methods and data were added. Developments increasingly involved mathematics, introducing Napier's logarithms and the Gunter scale and logarithmic trigonometrical functions. As a result, 'arithmetic navigation' advanced and the use of the common log for measuring speed became standard.[14] Mathematical and astronomical theories concerning navigation flourished in the seventeenth century, but it was not until the eighteenth century that these practices were applied by sailors to improve navigational practices.[15] By then, over fifty different authors had contributed to the stock of manuals, predominantly in English, Spanish, Portuguese, French and Dutch. These were often copied from older manuals and featured obscure explanations which sailors often did not understand, reducing the tacit skills of sailors to 'automatic adherence to rules of thumb'.[16]

Later eighteenth and early nineteenth century editions were often divided into two main sections. The former focused on basic mathematical principles (arithmetic, logarithms, sine, tangents, degrees, minutes, trigonometry); geography and astronomy; different sailing techniques (plane, Mercator, middle latitude, traverse); the construction and use of Mercator's chart; winds, tides, tables of finding the time of high water at any place; description and use of nautical instruments (log-line and half-minute glass, Hadley's

[14] Charles H. Cotter, 'A Brief Historical Survey of British Navigation Manuals', *Journal of Navigation*, 36, (1983), p. 242

[15] Commander J. B. Hewson, *A History of the Practice of Navigation*, (Glasgow: Brown, Son & Ferguson, 1951), pp. 101-103

[16] Hewson, *A History of the Practice of Navigation*, p.102

quadrant, sextant) and how to observe distances; parallax, refraction, semi-diameter; compass variation, true amplitude, true azimuth; the method of keeping a ship's reckoning; rules for correcting dead reckoning; and a journal example. The latter explained the various astronomical methods for determining latitude and longitude. Navigators looking to improve their accuracy in navigation by applying mathematical and astronomical rules could turn to subject specific publications. These related to specific instruments (quadrant, reflecting circle, compass, chronometer, Gunter scale); methods for determining latitude and longitude (Equal Altitudes, lunars, chronometers, position line); astronomical observations (finding azimuths, ex-meridian observations, hour angles) and specific data required for solving nautical problems (refraction, parallax, spherical trigonometry, simplified or new methods of calculation).

These developments not only transformed how navigation was practised at sea; they also led to the formation of the Royal Mathematical School, Christ's Hospital (RMS) in London. Established by Charles II in 1673, the RMS was the first school to teach boys, aged between twelve and sixteen years, mathematics and navigation. Perhaps unsurprisingly, many of the individuals associated with the RMS had close links with the Royal Society and the Royal Observatory. Samuel Pepys, Jonas Moore, Robert Hooke, Isaac Newton, Christopher Wren, John Flamsteed and Edmond Halley all contributed to its establishment. Hooke, Newton, Wren, Flamsteed and Halley were all involved with the content and structure of the curriculum.[17] This is significant as it underlines how important these individuals felt that mathematics and astronomy were for navigation, in particular for longitude determinations. Margaret Schotte argues that the RMS was 'shaped by an elite

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[17] Nerida F. Ellerton and M. A. Clements, *Samuel Pepys, Isaac Newton, James Hodgson, and the Beginnings of Secondary School Mathematics: A History of the Royal Mathematical School Within Christ's Hospital, London 1673-1868*, (New York: Springer, 2017), pp. 13-20

group of naval administrators and governors who stressed math and science', who preferred intellectual education above practical training.[18]

James Hodgson (assistant to Flamsteed at the Royal Observatory between 1696 and 1702), John Robertson and William Wales were influential Masters during the eighteenth century.[19] It was for the curriculum of this school that John Robertson wrote his first edition of *Elements of Navigation* in 1754.[20] Students learned according to the cyphering tradition; extant cyphering books examined by Ellerton and Clements showed that they were largely copies of Robertson's *Elements*.[21] After passing their exams at Trinity House based on Robertson's *Elements,* the boys would proceed to a seven-year apprenticeship on a merchant or naval vessel. These boys would thus enter the Navy as a King's Boy, or 'Volunteer per Order'. As an Admiralty nominee, captains could not refuse such an appointment. Young men who entered the Navy via this pathway were often poor or the sons of deceased captains; their prospects were that of a warrant officer, the master charged with navigating the ship.[22]

Another shore-based education institution, established in 1733, was the Royal Naval Academy (RNA) in Portsmouth. Dickinson has traced the motive for establishing the Academy to the somewhat failed scheme of the naval schoolmaster, introduced in 1702 with the intention of teaching future officers on board ship by midshipmen who would receive additional pay for taking on this duty. To remedy this, the Admiralty proposed that the Academy teach 'the sons of noblemen and gentlemen aged between 13 and 16 year on admission'.[23] These students were to receive a 'broad spectrum of the academic and the

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[18] Margaret E. Schotte, *Sailing School: Navigating Science and Skill, 1550-1800*, (Baltimore: John Hopkins University Press, 2019), p. 102
[19] Ellerton and Clements, *A History of the Royal Mathematical School*, p. 25
[20] John Robertson, *The Elements of Navigation Containing the Theory and Practice*, (London: Printed for J. Nourse, 1754)
[21] Ellerton and Clements, *A History of the Royal Mathematical School*, p. 111
[22] Ibid, pp. 121-141
[23] H. W. Dickinson, 'The Portsmouth Naval Academy, 1733-1806', *The Mariner's Mirror*, 89:1, (2003), p. 19

practical [which stood in] marked contrast, not only to the narrow classical curriculum of the eighteenth-century public school, but also to the meagre diet provided by the naval schoolmaster afloat'.[24] The practical aspect of the curriculum took place in the dockyard. After spending two years at the Academy, the student progressed to sea, where although he might access the quarterdeck, he would be paid as an able-seaman and would only be awarded a midshipman's rank after two years of service. Via the Royal Naval Academy, the Admiralty attempted not only to combine theoretical and practical training, but to ensure ongoing training beyond the Academy. To promote this route, academy graduates could qualify for the lieutenant's exam after only four years of service at sea, rather than six years as was the general custom. But this was not their only aim; it was also an attempt at the centralisation and control of naval education, a struggle the Admiralty would continue well into the nineteenth century.

Figure 4.1: Royal Naval Academy, Portsmouth: panoramic view with an anchor. Aquatint by Hall, 1806, after I.T. Lee. Credit: Wellcome Collection. (Attribution 4.0 International (CC BY 4.0))

[24] Dickinson, 'The Portsmouth Naval Academy, 1733-1806', p. 19

Like the Royal Mathematical School, the Royal Naval Academy had close ties to the Royal Society, Trinity House, the Board of Longitude and the Royal Observatory. These links can again be found in the Masters of the academy. John Robertson held the position between 1755 and 1766, using his *Elements of Navigation* as part of the curriculum. Robertson's assistant at the Academy, Robert Waddington, had served as an observer with Nevil Maskelyne on the 1761 transit of Venus expedition and on his return promoted the lunar distance method through publications and private instruction.[25] George Witchell, master between 1766 and 1785, was a Fellow of the Royal Society, had received £300 from the Board of Longitude, and had 'assisted Cook with calculations and chronometer calibrations' after his second voyage.[26] Witchell's assistant, John Bradley, nephew to the Astronomer Royal, also had experience at sea trialling lunar distances under Captain John Campbell on HMS *Chatham.* In 1784, William Bayly, former assistant to the Astronomer Royal, was appointed as astronomer by the Royal Society to observe the transit of Venus at the North Cape in 1769 and served alongside Wales on Cook's second voyage of discovery. Bayly was Master during the final decades of the Royal Naval Academy (1785-1807), before it was reconstituted under James Inman as the Royal Naval College. For other young hopefuls, private academies also provided education and training for boys looking to enter the Navy. One such establishment was Dr Burney's Naval Academy, situated at Gosport in Portsmouth, which enjoyed royal patronage and also received students from wealthy families.[27] Despite its name (and Burney's claim that he trained 'a greater number of young officers for the sea service than any other individual'), boys at the academy were taught a wide range of subjects and although many did enter the navy, former pupils also joined the Marines or the Army. George Francis Lyon,

[25] Jim Bennett, 'Mathematicians on Board: Introducing Lunar Distances to Life at Sea', *British Journal for the History of Science*, 52, (2019), pp. 65-83
[26] Dickinson, 'The Portsmouth Naval Academy', p. 21
[27] A. Macdermott, 'Dr Burney's Royal Academy at Gosport', *Mariners Mirror*, 51, (1965), p.57-59

appointed by Parry to command the *Hecla* during the second Arctic expedition, attended Burney's academy.

Both the Royal Mathematical School and the Royal Naval Academy faced somewhat similar problems. The curriculum was seen as too theoretical and too advanced for the young students. Many officers also believed that effective training could only take place on board ship. For officers 'it was immersive, experiential, and practical; it was delivered on an informal, ad hoc basis on board ships in commission'.[28] Although this approach may have produced good seamen, the Admiralty's problem was that it 'did not ensure that they were gentlemen'.[29] The curriculum at the RNA thus included subjects aimed at a balance between these two aspects; the ultimate goal was to establish a training scheme for gentlemen officers.

What the Royal Mathematical School, the Royal Naval Academy and private academies had in common was that the curriculum for navigation was based on the manuals that were so prolific at the time. Burney is significant here because in 1815 he revised William Falconer's *Universal Dictionary of the Marine,* a reference work for navigators and shipbuilders.[30] Within the section on navigation, Burney elaborated on navigational manuals, and listed which he thought were the best for pursuing navigation. Examining all the manuals in circulation during the late eighteenth century is beyond the scope of this thesis and only a small selection of manuals has been studied here. Given his position as a naval instructor and his knowledge of maritime affairs, Burney's recommendations offers a good way of selecting those manuals that, according to Burney at least, were most relevant. Burney thought

[28] Evan Wilson, Jakob Seerup and AnnaSara Hammer, 'The Education and Careers of Naval Officers in the Long Eighteenth Century: An International Perspective', *Journal for Maritime Research,* 17:1, (2015), p. 27
[29] Ibid, p. 30
[30] William Falconer, *A New Universal Dictionary of the Marine*, 1815 Edition, (Cambridge: Cambridge University Press, 2012)

Robertson's *Elements of Navigation* was the manual 'best adapted for teaching the art of navigation in a scientific manner'.[31] William Norie, Andrew Mackay, and John Hamilton Moore's general navigation manuals were the most common treatises used at sea as they were 'merely calculated for practical seamen, who have not studied the theory; and on that account are published in a small convenient size, and at a low price'.[32]

The most striking element of these early manuals is their lack of chronometric instruction. The first description to appear was in the 1772 edition of Robertson's *Elements*. The manual described nine methods for finding the longitude (by a current; by the course and distance; by the variation chart; by a perfect time-keeper; by the Sun's declination; by the Moon's culminating; by eclipses of Jupiter's Satellites; by eclipses of the Moon; by occultation of stars). Time-keepers (i.e. chronometers), the 'mechanical solution' to finding longitude, were described as too expensive to allow for general supply to naval ships and potentially unreliable, as 'to whatever degree of perfection such a movement may be bought … every mechanic instrument must be liable to be injured by various accidents'.[33] No rules or examples were given on how to determine the error and rate, or the longitude with the instrument. The author hoped that astronomical methods might be improved so they could also be used from 'time to time'.[34] Robertson's *Elements* ran through a further four editions (with the last published in 1805) but the chronometric section was never updated.

Moore described the principle of longitude by chronometer a decade later in *The Practical Navigator* as follows: 'nothing more is wanted than to find apparent Time at the Ship, and to correct it by the Equation of Time; the Difference of this Time so correct, and that given by the Watch, turned into Longitude, will be the difference of Longitude between

[31] Falconer, *A New Universal Dictionary of the Marine*, p. 309
[32] Ibid, p. 310.
[33] Robertson, *Elements of Navigation*, 1772, Book IX
[34] Robertson, *Elements of Navigation*, 1780, Book IX, pp. 291-292

the Ship's Meridian and that Meridian to which the Watch was set'. Moore thus described the principle, but only in the introductory text on longitude. He omitted it as a method of determining longitude, 'as,' he stated, 'Watches, though made upon the best Construction, are subject to some internal Irregularities, and apt to be otherwise affected by Heat and Cold, the Mariner may well be anxious to determine his Longitude at Sea by celestial Observations'.[35] Other descriptions appeared in the 1790s, noticeably in publications specifically related to nautical astronomy for finding latitude and longitude. Mackay was the first to do so in his *Theory and Practice of Finding the Longitude at Sea or Land*, first published in 1793. Mackay was Maskelyne's original choice to replace the astronomer on the Vancouver expedition, but he appointed Inman due to Mackay's 'stalling'.[36] The work was in two volumes; the first containing the method of finding longitude, the second containing the necessary tables. The main focus of the book, after explaining the principles of longitude and angle measuring instruments, was on the lunar distance method. Chronometry instruction was placed in Book IV 'Containing various other methods of determining the Longitude of a Place'.[37] Just as Wales and Moore before him, Mackay noted the irregularity of timekeepers and their high price as the main objection to their use, stating that 'if a chronometer could be constructed, so as to go uniformly when placed in every different position, and under different degrees of heat, then would this method of finding longitude be a most valuable acquisition to the navigator'; however, due to doubts concerning their accuracy, they were

[35] John Hamilton Moore, *The Practical Navigator and Seaman's New Daily Assistant Being an Epitome of Navigation*, ninth edition, (London: Printed for B. Law and Son, 1791), p. 228
[36] Rebekah Higgitt, 'Equipping Expeditionary Astronomers: Nevil Maskelyne and the Development of 'Precision Exploration', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald, and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), p. 35
[37] Andrew Mackay, *The Theory and Practice of Finding the Longitude at Sea or Land*, Volume I, (London: Printed for J. Sewell, 1793), p. xii

'chiefly used for experiment, or to connect observations, for which purpose they certainly make a valuable appendage to a set of nautical instruments'.[38]

John William Norie, a chart maker and teacher of navigation at a nautical academy on Leadenhall Street in London (which also sold charts and nautical instruments), published *A Complete Epitome of Practical Navigation* in 1804.[39] Norie expanded on the necessity of determining an error and rate, as 'if its error at the given meridian be known on a certain day, and also its rate, or daily gain or loss, we can thence deduce the time at that meridian as well as if the hands of the watch actually pointed it out; provided that it goes uniformly, which is all that is essential in the motion of a time-keeper'.[40] The maker, or whoever cared for the instrument, was to supply this rate and error; alternatively, they could be established by single or Equal Altitudes of the Sun. The regularity of the watch could be determined by regular celestial observations. Norie then explained the method for finding the longitude by chronometer supplemented with four examples, as was the tradition in navigational manuals. The rules were simple:

1. Note several altitudes of the Sun and their time by the chronometer.
2. Determine the Mean Time of these several observations and correct it for rate and error.
3. Use the latitude, true altitude and declination to determine the apparent time and Mean Time of the ship. The difference between the time by the chronometer and the Mean Time determined by the altitudes of the Sun is the longitude.

[38] Andrew Mackay, *The Theory and practice of Finding the Longitude at Sea or Land*, (London: Printed for J. Sewell, 1793), Volume I, p. vii
[39] Susanna Fisher, 'John William Norie', *Oxford Dictionary of National Biography*, (online ed.), Oxford University Press. Last accessed 16 September 2020: https://doi.org/10.1093/ref:odnb/20256
[40] John William Norie, *A Complete Epitome of Practical Navigation*, (London: Printed for the Author and William Heather, 1805), p. 238

EXAMPLE II.

January 27, 1809, in latitude 6° 58′ N. the following altitudes of the Sun's lower limb were observed, (the eye being elevated 18 feet,) corresponding to the times shewn by a time-keeper, whose error and rate were established at Bombay, January 16, having on that day been found 5^h 17^m 42^s too slow, and losing 5.5ˢ daily: required the longitude in.

Times. h m s	Alts. ° ′		° ′ ″		s
23 4 26	18 42	Obs. alt. ☉'s low. l.	18 11 40	Daily loss -	5.5
7 17	18 12	Semidiam. 16′ 16″	+ 12 12	Days from Jan. 16 to Jan. 27 -	11
9 30	17 41	Dip - 4 4			
3) 21 13	54 35	Sun's app. altitude	18 23 52		60)60.5
		Refraction -	— 2 50		
23 7 4	18 11 40			Lost since Jan. 16	1ᵐ 0.5ˢ
5 17 42 Original err.		Sun's true altitude	18 21 2		
				Sun's declination Jan. 27	18 28 53
28 24 46				Corr. for time before noon	+ 15
+ 1 1 Lost since Jan. 16.					
				Sun's reduced declination	18 29 8
28 25 47 Mean time at Bombay, aft. n. Jan 26.					90
4 51 38 Long. of Bombay in time, E.					
				Sun's polar distance	108 29 8
23 34 9 Mean time at Greenwich Jan. 26.					

True altitude -	18° 21′		
Polar distance -	108 29	- - Co-secant	0.02300
Latitude - -	6 58	- - Secant -	0.00322
Sum - -	133 48		
Half sum - -	66 54	- - Co-sine	9.59366
Remainder - -	48 33	- - Sine -	9.87479
		Const. Log.	5.30103
	h m s		
Apparent time at ship -	4 31 50	- - Log. rising	4.79570
Equation of time -	+ 13 9		
Mean time at ship -	4 44 59		
	24		
Ditto from noon Jan. 26	28 44 59		
Mean time at Greenwich	23 34 9		
Longitude in time -	5 10 50 = 77° 42′ 30″ East.		

Figure 4.2: Example of a longitude calculation, Norie, *A Complete Epitome* (1805) p. 240.

In theory, this was indeed a simple method. What is more interesting here is that earlier in the manual, under the method for finding the longitude by lunar distances, eight and a half pages were dedicated to finding the time at sea and the error and rate of the watch. This was also the case in the manuals by Robertson, Moore, and the revised editions of Moore's manual by Bowditch and Kirby. Robertson explained the process as early as 1772 in Book IX detailing the 'Day's Work'. In most of the late-eighteenth-century manuals, these explanations were always included within the description for the lunar distance method. This would suggest that if navigators were taught according to these manuals, most of the basic steps for determining longitude by chronometer would have been learnt as part of the lunar distances. It would also imply that competent users of chronometers had acquired many of the basic mathematical and astronomical skills that underpinned the method through the instruction of lunar distances. What these manuals thus show is how these methods relied on one another to be practical or useful at sea. Of these well-known manuals published in the first decade of the nineteenth century (Moore, Robertson, Kirby and Bowditch, Norie, Mackay), the consensus would imply that lunars were, in theory, considered the best method for finding longitude. The chronometer, found its place amongst the 'other methods', such as finding the longitude by a variation chart or by eclipses of Jupiter's Satellites.

Some Notes useful to those who have Chronometers at Sea

Andrew Cook has examined Dalrymple's publication in relation to his collaboration with chronometer maker John Arnold and his position as Hydrographer to the East India Company (1799-1808).[41] The motivation for his appointment as Hydrographer was the loss of East Indiaman *Colebrooke* in 1778. Although a known danger since 1745, subsequent wrecks on the Anvil Rock in False Bay at the Cape of Good Hope provided the impetus for the company to appoint Dalrymple at an annual salary of £500 to improve hydrographical information. Dalrymple planned to construct twenty-seven small-scale charts to improve navigation to the Indian continent. Connecting these charts could only be done by determining the relative longitudes between them and Dalrymple thought that time-keepers and lunar observations could be used to achieve this aim. Dalrymple worked closely with Arnold and promoted his

[41] Andrew S. Cook, 'Alexander Dalrymple and John Arnold: Chronometers and the Representation of Longitude on East India Company Charts', *Vistas in Astronomy*, 28, (1985), pp. 189-195

instruments to be used in these surveys. It was therefore shortly after his appointment in 1779 or 1780 that Dalrymple's first instructions relating to chronometers were circulated, followed shortly after by an eight-page pamphlet advising on their use at sea. He was instrumental in a survey conducted by East Indian Captain John McCluer in 1786 of the west coasts of India. In addition to one box and two pocket chronometers sent to Bombay for the survey were copies of a four-page manual entitled *Instructions concerning the Chronometers, or Time-keepers, sent to Bombay, 1786*. One year later, Dalrymple added additional instructions for observations and the Equation of Time.

A combination of these earlier instructions formed the twelve-page instructions under examination, which appeared in 1788.[42] It consisted of three parts. The first part described the actual pocket chronometer and included how to open it; how to start it once stopped; how to set the hands, and finally warned users not to hold a magnet in the vicinity of the instrument. Dalrymple's advice on winding had less to do with ensuring the good function of the instruments, but more to ensuring the behaviour of the user as he cautioned 'where there are more Chronometers than one, it will be proper to wind up one at Noon, the other at 8 o'clock at Night … always comparing them before and after winding up, and noting that comparison, to prevent the accident of letting them run down, by forgetting to wind them up, which is not likely to be forgot twice in one day'.[43] Dalrymple included instructions on comparing the chronometers before and after taking five observations for the time, emphasising that these should be noted, but did not include advice on how the observations for time should be taken or calculated. This was explained in the second section of the pamphlet, entitled *Some Notes useful to those who have Chronometers at Sea.* This six-page part of the pamphlet started with explanations of some basic concepts in astronomy: the

[42] Cook, 'Alexander Dalrymple and John Arnold', pp. 189-195
[43] Alexander Dalrymple, *Instructions Concerning Arnold's Chronometers or Time-keepers*, (Pamphlet, 1788), p. 1

difference between civil, astronomical and nautical time; how apparent solar time and Mean Time related to one another; that the chronometer carried Greenwich Mean Time and how to determine whether the position was east or west of Greenwich depending on whether the chronometer was ahead of or behind GMT; explanation of the Equation of Time and how it was calculated (this section takes up almost two pages of the document); clarification of the rate and error of chronometers and how these could be calculated to correct the longitude by chronometer and a further half page devoted to explaining how to determine the error of the chronometer by a known longitude. This section concluded with instruction on observations for time, advising users to take five altitudes to detect any observational errors. Dalrymple stressed that the altitudes for finding the time were 'a daily operation, *without which* the Chronometer, however exactly it goes, can give no *Information* of the *Longitude*'.[44] The final four-page section instructed how the local time could be determined by observations of the Sun's altitude. This was the basic astronomical and mathematical theory behind the calculation of local time and how from this the longitude could be found by chronometer. This section emphasised how to apply the declination of the Sun's altitude in the calculation, as the declination given in the tables required correction to the meridian of the observer. What this part of the instruction emphasised was that the local time, such a crucial component for longitude by chronometer, was entirely dependent on the tables based on the Greenwich meridian, thus tying the chronometer method firmly to the Royal Observatory via the *Nautical Almanac*.

A method; plain and simple

In 1794 Wales published a 155-page manual entitled *The Method of Finding the Longitude at Sea by Time-keepers*. According to Wales the method was, 'too plain to be misunderstood,

[44] Dalrymple, *Instructions Concerning Arnold's Chronometers or Time-keepers*, p. 8

and too simple an operation to require rules for putting it in practice', the 'only difficult part of the business' was finding the rate of the time-keeper.[45] Wales published his *Method* as a reaction to the opinions of an authority that had brought 'time-keepers into disrepute, and toward defeating the endeavours of the Board of Longitude'.[46] The authority in question was Thomas Mudge Jr, who had been involved in a dispute with the Board of Longitude and with Nevil Maskelyne concerning his father's timekeepers. The resulting publication accused Maskelyne of not giving their time-keepers a fair trial at Greenwich. This public dispute deserves mention as the problems raised remained essential to navigational developments until well into the nineteenth century. One point to note is that Mudge and his ally Franz von Zach (head of the Gotha Observatory) suggested that the Royal Observatory was biased in its chronometer trials because Maskelyne and his assistant, as astronomers, would be promoting the lunar distance method. Like Harrison, Mudge and Von Zach saw the methods as competing rather than complementary techniques and challenged the Observatory's authority to judge these trials. The Select Committee appointed to investigate the matter could only conclude that 'no judgement can be formed of the exactness of any timekeeper by theoretical reasoning upon the principles of its construction, with such certainty as with safety to be relied upon, expect it to be confirmed by experiments of the actual performance of the machine'.[47]

The Method can thus be understood as Wales' retaliation against Mudge, asserting his authority as an astronomer to judge the merits of a chronometer. Officers supplied with chronometers should follow Wales' instructions for rating the instruments and if this was

[45] William Wales, *The Method of Finding the Longitude at Sea by Time-keepers*, (London: Printed by C. Buckton, 1794), p. iii
[46] Wales, *The Method of Finding the Longitude at Sea by Time-keepers*, preface, p. iv
[47] Report from the select committee of the House of Commons 1793 quoted in Eóin Phillips, *Making Time Fit: Astronomers, Artisans and the State, 1770-1820*, Unpublished PhD, University of Cambridge, (2014), p. 198

done properly, then it was not the method, but the watch itself that was at fault.[48] Wales claimed that 'precisely because timekeepers were so complicated, and because they were already in use at sea, the problem of longitude was actually a problem of regulation and rating' and only 'astronomical surveillance' orchestrated from the Royal Observatory could perform this duty.[49] The subsequent decades of chronometer use would prove Wales both right and wrong: right to state that a major problem was regulation and rating; wrong to think that the method and operation was 'too plain … and too simple'.

In his preface, Wales stressed that what he hoped to achieve with this publication was: '[to] remove the stigma which, for private purposes, has been unjustly thrown on these valuable machines'.[50] The stigma he alluded to was trepidation and difficulty relating to the rate and error of timekeepers and thus ultimately their reliability. Wales' aim was to instruct users on how easy this was. 'It will be shown in the following tract, that there is nothing more simple in itself, or more readily performed, than finding the rate, which a time-keeper goes at … [for] every one, who is conversant with astronomical observations', conveniently forgetting that most sailors were not. He continued that if 'irregularities in a watch's going be very great, or the period in which its irregularities return be long, or infinite, I grant that this method of deriving a rate is useless; and so will every other method be … but the method is only useless because the watch is so'.[51] The problem with timekeepers then, was finding the rate and error for those who were *not* conversant with astronomical observations, which at the time of writing was in all probability a majority of officers at sea.

Wales's method was divided into eighty-three articles. Articles 1 to 26 (16 pages) outlined astronomical functions and definitions. These ranged from simple definitions, such

[48] Phillips, *Making Time Fit*, pp. 196-200
[49] Ibid, p. 199
[50] Wales, *The Method of Finding the Longitude at Sea by Time-keepers*, preface, p. v
[51] Ibid, p. ix

as a meridian or the horizon, to explaining the fundamentals of spherical trigonometry that formed the basis for astronomical position finding. These articles also explained and demonstrated how to determine the Equation of Time, the Sun's longitude and the declination using the *Nautical Almanac*. Articles 27 to 36 (11 pages) detailed how to find the local Mean Time at the ship and Greenwich time by the watch. Wales used this section to explain how to rate the watch. This could be done by observations of the Sun's altitude, using Hadley's quadrant. Wales included this method 'because it may be put into practice by every seaman, without introducing the use of any instrument, or observation, which he is not already necessarily acquainted with' and that it could be performed 'if care and skill be exerted, with tolerable exactness'.[52] Despite this, Wales did not recommend it for long voyages, even if used with the 'utmost skill'.[53] Articles 36 to 75 (42 pages) described the more precise method of determining the rate of the watch, with a transit instrument as astronomers did in fixed observatories: thirty pages were dedicated to the description and use of the transit instrument. The method of rating by Equal Altitudes was described in articles 76-82 (8 pages). Finally, article 83 explained how to 'find the longitude at sea by a Time-keeper', covering only four pages, of which two included worked examples. The point that must be made here is that although finding longitude was in theory relatively simple, it still required astronomical and mathematical skill.

The majority of the method was thus dedicated to the astronomical procedures that were required to establish the rate of the chronometer. Each method was directed at a particular user or voyage, depending on the ability or duration. Wales recommended observations of the Sun's altitude for the use of general seamen where 'tolerable exactness' sufficed'.[54] If greater exactness was required, Wales advised using a transit instrument, but

[52] Wales, *The Method of Finding the Longitude at Sea by Time-keepers*, p. 28
[53] Ibid, p. 28
[54] Ibid, p. 23

added that this required some experience of practical astronomy and additional time to set up the transit instrument. Meridional transits of stars could be used for greater accuracy when there was less time or experience to set up the transit instrument. Finally, for those not equipped or familiar in the use of the transit instrument, Equal Altitudes would also give fairly accurate results.

Phillips has argued that Wales' M*ethod of Finding the Longitude at Sea by Time-keepers* must be seen in the context of his post-voyage career, where the 'range of activities that these astronomers became involved in were united by the aim of the longitude astronomers to situate themselves as mathematical experts and define distinct roles in which they could act for the state'.[55] Whatever the reason Wales had for publishing, and even if this was not (solely) as an instruction manual for users, it still remains one of the few in circulation at the time that detailed any kind of instruction in depth. What should also be noted, is that despite Wales' familiarity with the instruments and considering the publication of his *Method*, he chose not to update the section on chronometers in his revised editions of Robertson's *Elements* in 1780 and 1796. We may assume that these were written with different users in mind, and that those learning from *Elements* were not expected, by Wales at least, to be in charge of chronometers when they later went to sea.

What both Dalrymple's and Wales' publications show is that although the chronometer may be seen as the mechanical solution to longitude and lunar distance the astronomical, the distinction is moot as the chronometer method was still profoundly astronomical. Wales had been dismayed by the lack of astronomical knowledge on the *Resolution*, and the astronomical basics formed a large part of his method.[56] The amount of astronomical explanation and instruction included together both show that these were

[55] Phillips, *Making Time Fit,* p. 166
[56] Ibid*,* p. 169

considerable problems to be overcome if the chronometer was to be put to use. Rate, error, the Equation of Time, Solar time and Mean Time were all new concepts for many of these early users. This, alongside the cost of the instruments, may have been a big hurdle for users to overcome. These two publications also show how the interdependence of the chronometer on astronomical instruments and nautical tables. Although in essence the 'longitude by chronometer' rule was simple, it was underpinned by complex and advanced mathematical and astronomical ability.

What is clear from these manuals in the context of these educational institutions is that they formed an important basis for the education of potential future naval officers. Lessons were dictated from textbooks, transcribed and memorised, supplemented by hands-on learning with instruments. In addition, mock exams were often included within these manuals.[57] Authors of these manuals were generally not experienced seamen, although some had spent some time at sea. They were generally skilled mathematicians or astronomers with close ties to the Royal Society and the Royal Observatory. The users they wrote for were not yet officers or captains of Royal Navy ships, but young boys who did not always pursue a career at sea.

In the late eighteenth century, this lack of instruction may not have been problematic for Royal Navy voyages, as the use of both methods was limited to exploration and surveying voyages. Unlike routine voyages of navigation, these voyages were often commanded by captains already skilled in navigation and surveying and who were often accompanied by an astronomer whose duties included determining the longitude on land.[58] With the skills these astronomers brought to the voyage, they were able, and expected, to instruct officers in the

[57] Schotte, *Sailing School: Navigating Science and Skill, 1550-1800*, pps. 106-107, 110-156
[58] Francis Lucian Reid, 'William Wales (ca. 1734-1798): Playing the Astronomer' *Studies in, the History and Philosophy of Science*, 39, (2008), pp. 170-175

astronomical techniques necessary for lunar observations and chronometers.[59] Higgitt has pointed out that 'these men were . . . the means by which the practices valued by Maskelyne were embedded in Royal Navy survey voyages. His alignments of instruments, projects, observers and the interests of the Royal Society and Navy helped shape the nineteenth-century role of the scientific servicemen'.[60]

Early adoption of the chronometer at sea was thus promoted and supported by the Board of Longitude, the Royal Society and the Royal Observatory. As was seen in the publications by Wales and Dalrymple, for the chronometric method to succeed, users were required to learn astronomical and mathematical skills to which navigators were in general not accustomed. Astronomers were thus vital to introducing these methods into Royal Navy practices.[61]

It remains important to state that this formed only the basis of an officer's education, and that their training continued on board ship. For many, this took place under different captains on board a variety of vessels. Others would serve the same captain for a number of years, often alongside the same young gentlemen they first came on board with. After serving six years at sea they would sit their lieutenant's exam. Moore's *Practical Navigator* formed the basic standard to pass this examination but was later replaced by Mackay's *Complete Navigator.* Mackay was examiner for Trinity House, the East India Company and the Royal Mathematical School at Christ's Hospital.[62] Miller touched upon the officer training for the East India Company's training of officers, noting that 'the degree to which these officers were educated in navigation at institutions designed for the purpose, including the

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[59] Harold B. Carter, 'The Royal Society and the Voyage of HMS 'Endeavour' 1768-71', *Notes and Records of the Royal Society of London*, 49, (1995), p. 258
[60] Rebekah Higgitt, 'Equipping Expeditionary Astronomers', p. 28
[61] Richard Dunn and Rebekah Higgitt, *Finding Longitude: How Ships, Clocks and Stars Helped Solve the Longitude Problem*, (London: Harper Collins, 2014), p. 141
[62] E. G. R. Taylor, *The Mathematical Practitioners of Hanoverian England, 1714-1840*, (London: Cambridge University Press, 1966), p.88

Royal Mathematical School at Christ's Hospital, is an important question. For most, the Company's elaborate system of qualification for officers ensured a fairly rigorous training, that was provided through a complex network of teachers and examiners and through training aboard ship, rather than by a single institution'.[63] To understand how an officer became a skilled mathematical and astronomical navigator, competent in the use of instruments, the next section of the chapter examines practices on board ship.

At sea: experimental practices 'in the wild'

The education and training of aspirant officers was inconsistent and unregulated during the late-eighteenth- and early-nineteenth centuries. The majority of officers entered the Navy through a captain's patronage. Aspiring officers were entered in the muster book as a captain's servant, and after serving six years at sea, of which at least two were at the rating of a midshipman or master's mate, could sit the lieutenant's examination from the age of nineteen.[64] This was the general course of entry for young gentleman of a certain social rank. For those not destined for the quarterdeck, a career path would typically start in boyhood, with aspirations for a warrant rank. From here, individuals of exceptional professional ability, or those who distinguished themselves in battle, could obtain a commissioned officer's position, as the lieutenant's examination was open to any sailor with the qualifying sea time. Individuals entering as a 'College Volunteer', those who passed through Admiralty control via the Royal Naval Academy, accounted for as little as two percent of entrants.[65] Within this

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[63] David Phillip Miller, 'Longitude Networks on Land and Sea: The East India Company and Longitude Measurements 'in the Wild', 1770-1840', in: *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds. (Basingstoke and New York: Palgrave Macmillan, 2016), p. 232
[64] Nicolas A. M. Rodger, *The Wooden World: Anatomy of the Georgian Navy*, (London: Collins, 1986), p. 262
[65] H. W. Dickinson, *Educating the Royal Navy: Eighteenth- and Nineteenth-Century Education for Officers*, (London and New York: Routledge, 2007), p. 39

system, the other ninety-eight percent of young gentlemen entered the Navy through patronage, outside Admiralty awareness. The lieutenant's exam was either overseen by the Navy Board in London, before a board of three captains; or arranged by a Commander-in-Chief overseas before a similar board. As a result, the Admiralty had no control or even knowledge of the number of entrants until they applied for the lieutenant's exam, and this knowledge only applied to those sitting the exam at home.[66] This lack of oversight caused problems that the Admiralty wanted to address: they had no idea how many young men entered the Navy; they had no control over the social make-up within the rankings; and they were unable to control and regulate individual training and education.

The end of the Napoleonic Wars signalled a change. For the Royal Navy, peacetime was a time of improvement, not only in navigation, but also in shipbuilding, design and gunnery. Trade was vital for Britain's prosperity, and the Royal Navy protected Britain's commercial interests and trade expansion through naval dominance.[67] This was to have an effect on the education of officers. Within the eighteenth-century training system, tensions existed between professional (naval) rank and social rank. Skilled seamen may have been fit for command professionally but not socially: this caused conflicts and complicated on-board hierarchies, which challenged authority and discipline. The mass influx of recruitments during the war had allowed individuals from other social backgrounds to penetrate the officer ranks. Towards the end of the Napoleonic Wars, the Admiralty pushed through regulations and reforms in an attempt to centralise and control the selection and appointment of officers. Cavell identified the period between 1801 and 1831 as a period 'that signalled the beginning

[66] Samantha A. Cavell, *Midshipmen and Quarterdeck Boys in the British Navy, 1771-1831*, (Woodbridge: The Boydell Press, 2012); Michael Lewis, *The Navy in Transition: A Social History 1814-1864*, (London: Hodder and Stoughton, 1965); Nicolas A. M. Rodger, 'Commissioned Officers' Careers in the Royal Navy, 1690-1815', *Journal for Maritime Research*, 3:1, (2001), pp. 85-129
[67] Andrew D. Lambert, *The Last Sailing Battlefleet: Maintaining Naval Mastery 1815-1850*, (London: Conway Maritime Press Ltd. 1991), p. 1

of a slow but inexorable march towards a nineteenth-century navy officered in large part by the social elite'.[68]

After 1815, the high demand for appointments and the shortage of opportunities led to 'social exclusivity in the midshipman's berth'.[69] Aristocratic and peer influence once again became the determining factor to penetrate the ranks. Well-born sons were required to learn hands-on skills in seamanship and to receive an education befitting a gentleman.[70] Cock points out that 'partly *because* of its traditionally amateur standing, science was largely a gentlemanly pursuit, and therefore a fitting "occupation" for a gentleman-officer'.[71] This aided the development of what Miller terms the scientific serviceman: 'naval officers who took part in voyages launched by the Admiralty on which they did scientific work'.[72] Scientific work during the early nineteenth century increasingly turned away from natural history towards the physical sciences, in what some authors term Humboldtian Science: 'the collection of large amounts of data, often using precision instruments, from global or regional surveys'.[73] A gentlemen's character guaranteed the correctness of his data: '[the] ability to perform precise and accurate measurement ensured that the experimenter was of good moral standing, while the genteel character and reputation of the man ensured others that his observations and data were reliable'.[74] Thus, for young gentlemen seeking rewards, scientific achievement could lead to medals, honours and a fellowship of the Royal Society. By 1848, 'good scientific work' received 'pecuniary reward of promotion' from the

[68] Cavell, *Midshipmen and Quarterdeck Boys*, p. 215
[69] Ibid, pp. 209-210
[70] Evan Wilson, Jakob Seerup and AnnaSara Hammar, 'The Education and Careers of Naval Officers in the Long Eighteenth Century: An International Perspective', *Journal for Maritime Research*, 17:1, (2015), pp. 17-33
[71] Cock, 'Scientific Servicemen in the Royal Navy', p. 110
[72] David Philip Miller, *The Royal Society of London 1800-1835: A Study in the Cultural Politics of Scientific Organization*, Unpublished PhD, University of Pennsylvania, (1981), p. 120
[73] Cock, 'Scientific Servicemen in the Royal Navy', p. 96
[74] Sophie Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, Unpublished PhD, University of Cambridge, (2014), p. 78

Admiralty.[75] Maskelyne's legacy thereby ensured that 'the best instruments would be used by trained, mathematically capable observers, asked to take repeated observations whenever opportunity was presented, to achieve the highest possible levels of accuracy'.[76] It is critical to understand these expectations, and thus *how* chronometers were used at sea in terms of this expected accuracy within certain user groups at sea.

The navy in transition

Lewis described the Navy that emerged from the Napoleonic Was as 'a force, at any rate, as forward-looking as its predecessor had been backward-looking'.[77] The latter part of this description could easily apply to William Fitzwilliam Owen, who stood firmly in the old world. Robert Brown remarked that with his 'stubborn individualism, his eccentricities, his tyrannical use of authority on board ship, and his willingness to act without authorization, Owen was not unlike most other British naval officers of the eighteenth century'; what made him unusual 'was that with the end of the Napoleonic wars naval practices slowly changed and he did not'.[78] Owen's biographer Burrow treats him more favourably, however, both biographies suggest he was a complicated figure.[79]

Born in 1774, William Fitzwilliam Owen was the illegitimate son of a well-connected family descended from respectable Welsh ancestors. His father died when he was four years old, leaving him at a military barrack in Madras. Owen was taken under the wing of his father's friend, Captain Sir Thomas Rich, who took him to sea, aged four, as a captain's servant. Owen returned to his father's birthplace in North Wales where he spent several

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[75] Cock, 'Scientific Servicemen in the Royal Navy', p. 110
[76] Higgitt, 'Equipping Expeditionary Astronomers', pp.3-6
[77] Lewis, *The Navy in Transition, A Social History, 1814-1864*, p.9
[78] Robert Thomas Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast, 1774-1857*, Unpublished PhD, University of Syracuse, (1972), pp. 238-329
[79] E. H. Burrow, *Captain Owen of the African Survey*, (Rotterdam: A. A. Balkema, 1978)

years at various boarding schools, before excelling at a mathematical academy in London. He returned to sea in 1778, again serving under Rich, now as a midshipman.[80] He was thirteen years old and prospects were good. It was a time when an officer's social background mattered less.[81] He would be eligible to sit the lieutenant's exam in 1793, on the outbreak of the French Revolutionary War. Chances of promotion were high. Unfortunately for Owen, these prospects did not materialise. His first set-back was a transfer and a demotion, to a captain's servant on board the *Zebra,* patrolling the Irish coast. Thanks to the friendship of Rich, Owen returned to the *Culloden* as a midshipman, but the experience left him bitter and he complained that success 'depended too much on prejudice, corrupt favoritism, family or party favor'.[82] Owen saw service throughout the Napoleonic Wars under the command of many reputable commanders, and was temporarily promoted to lieutenant.[83] But his 'arrogance' and belief that 'he was chosen by God' led him to challenge the authority of the captain he was serving under on the *Ruby*, Captain Henry Stanhope, so much so as to initiate a court-martial against Stanhope at the Cape of Good Hope.[84] The charges Owen laid against Stanhope were dismissed as 'frivolous, malicious, ill grounded and not supported'.[85] Stanhope then proceeded to court-martial Owen, who was found guilty of provocation and negligence of duty, which led to his discharge. Owen had managed to establish himself as 'a rigid disciplinarian, and one who was jealous of his newly-gained authority', rejecting 'all authority other than his own'.[86]

[80] Burrow, *Captain Owen of the African Survey*, pp. 1-35;
[81] Evan Wilson, *Social History of British Naval Officers, 1775 -1815*, (Woodbridge: Boydell Press, 2017), p. 108
[82] Owen quoted in Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, p. 24
[83] Rodney, Howe, St. Vincent, Hood, Colpoys, Collingwood and Nelson: Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, p. 22
[84] Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, p. 26
[85] Court-martial proceedings January-June, 1795, ADM 1/5332, quoted in Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, p. 27
[86] Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, pp. 34-35

The subsequent ups and downs of Owen's career are too numerous to record here, although it is important to understand how his background informed his character and opinions. Owen had to wait until 1797 for promotion to lieutenant, and not until 1811 did he make captain, after 23 years at sea. Unfortunately for Owen, rather than distinction in battle, the *Mayflower*, under his command between 1803 and 1808 in the East Indies, was one of few ships lost to the French during the wars. This left him imprisoned on Mauritius for twenty-two months, alongside Matthew Flinders, under whose guidance he studied astronomy, navigation and hydrography. Here, he also developed a theory of the use of rocket signals and timekeepers for determining differences of longitude. [87]

On return, Owen, like many other officers, faced unemployment. He found temporary employment with Hurd at the Hydrographic Office, translating descriptions of the Portuguese Coast. In 1815, Owen joined his brother Edward Owen in North America, where he was ordered by Croker to survey the Great Canadian lakes. Here he established himself as a competent, but not exceptional, surveyor. During the survey, Owen trialled the measurement of distance using rocket signals and chronometers, and submitted a paper on his idea to the Board of Longitude on his return but received no reply, possibly because the method had already been employed by Wales and Bayly during Vancouver's expedition.[88] His short-lived period at the Canadian Lakes was not without controversy (for which he appeared to have a knack), but he excelled when it came to training future hydrographers. Serving under Owen on the Canadian Lakes were Alexander Becher, Henry Bayfield and Alexander Vidal, all of whom proceeded to have respected careers within the surveying service. He put his method of rocket signals and chronometers into practice whilst surveying Lake Ontario and wrote about this method in an appendix that was published in Murdoch Mackenzie's

[87] Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast,* pp. 15-68

[88] Andrew David, 'Vancouver's Survey Methods and Surveys', in: *From Maps to Metaphors: The Pacific World of George Vancouver*, Robin Fisher, ed. (Vancouver: UBC Press, 2014), p. 53

Treatise on Maritime Surveying. Owen remained unemployed until he was given command of HMS *Leven,* blaming his years of unemployment on his lack of 'influential friends in the Admiralty', whilst this did provide him the opportunity to work under Hurd at the Hydrographic Office again.[89]

The survey of the East African Coast, undertaken by Owen and his officers between 1821 and 1826, would result in the loss of over half of the original crew to malaria Despite this, they surveyed 20,000 miles of coastline.[90] The survey ran from the Cape of Good Hope, through Mozambique to Cape Guardafui, the coast of Arabia, to Bombay and included Madagascar, and en route back to England, Owen was ordered to include the West Coast of Africa.

During his time at sea, Owen worked with many junior officers: some had studied under Inman at the Royal Naval College (Vidal and Becher), others had entered through more traditional pathways. Owen commented on their abilities during the first months of the voyage of the *Leven:* 'Although we had a great many young officers, yet in astronomical science most of them were mere novices, and almost all were destitute of that elementary knowledge by which it can be acquired', leading Owen to 'keep up a continued course of observations, both by day and night, during our stay, principally with a view to acquire the use of different instruments'.[91] Accompanying them was the schoolmaster, Charles Gepp Robinson, and an instrument maker Johan Baker to supervise the chronometers: no further information on the latter has been found.[92] Richard Owen, a lieutenant on board HMS *Leven*, wrote an 'Essay on the Management of Chronometers' which served as both an account of

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[89] Burrow, *Captain Owen of the African Survey*, p. 75

[90] Stuart Jennings,' Chronometers on the 1821-26 Royal Navy African Survey', *Antiquarian Horology*, 40 (2019), pp. 200-214

[91] William F. W. Owen, *Narrative of Voyages to Explore the Shores of Africa, Arabia, and Madagascar*, (New York: J. & J. Harper, 1833) Volume I, p. 17

[92] Burrow, *Captain Owen of the African Survey*, p. 86

their practices and as a guide for further use. The 'Essay' also underlined what Dalrymple and Wales had shown; namely that a considerable knowledge and skill of astronomical observation was necessary, but what Richard Owen additionally argued, was that the instruments themselves required careful management.

Initially, Owen claimed that 'it was impossible . . . not to have confidence in the results of eight chronometers going so well as those of both the *Leven* and *Barracouta* did at that time'.[93] After arriving at the Cape of Good Hope from Rio de Janeiro, the difference of longitude 'entitled them still to full faith', due to the 'accuracy with which our chronometer had gone so far'.[94] Owen knew that chronometers could benefit the surveying work that the *Leven* and the *Barracouta* were engaged in, but as the journey wore on, he became wary 'to place implicit confidence in it', being concerned that to do so 'might probably be fatal to the correctness and utility of our work'.[95] His caution was justified as 'not one of our nine chronometers kept its rate without fluctuation, produced either by change of weather, climate, or position'.[96] Actual practice thus required 'a great deal of care and attention' to prevent error.[97] As we have seen in the previous chapter, Owen was not issued with many 'good' chronometers.

William Owen may be recognised for his training of younger officers, but the credit for the hydrographical work should not lie solely with him. Owen, a fervent abolitionist, spent much of his time involving himself in local politics, attacking the slave trade and setting up protectorates.[98] Such activity took him away from the survey and much of the work was left

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[93] William F. W. Owen, *Tables of Latitude, and Longitudes by Chronometer*, (London: Hydrographic Office, 1827), p. 9
[94] Ibid, p. 10
[95] Owen, *Narrative of Voyages to Explore the Shores of Africa, Arabia, and Madagascar*, Volume I, p. 16
[96] Ibid, p. 16
[97] Owen, *Narrative of Voyages*, Volume I, p. 16
[98] Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, pp. 322-332

to the *Barracouta* and the tenders with Vidal, Boteler and Richard Owen. On his return to Britain, Owen's bills were turned down and he was charged for the missing and damaged equipment. Writing to Croker, he claimed 'his career had been damaged because "political change, and other circumstances . . . condemned me to see myself passed . . . by numerous inferior Officers"'.[99] He blamed 'the Hydrographic Department for "incompetence", and the Admiralty for being "a prey to pretenders of scientific ability" who were interested in "special schemes"'.[100]

Gentlemen of Science

As the Royal Navy was in transition, so also British institutions of science were undergoing change by the early nineteenth century. During the final two decades of Banks' presidency of the Royal Society, his input into others' exploration voyages increased. Under Banks, the Royal Society pursued the causes of the landed gentry and aristocracy; namely natural history, antiquities and agricultural improvement.[101] Against these interests, a group of reformers emerged, with interests in and a commitment to knowledge as a vocation. These gentlemen, members of the self-proclaimed 'Cambridge Network' – George Airy, Charles Babbage, John Herschel, George Peacock, William Whewell – moved away from natural history to pursue the physical sciences. Edward Sabine and Francis Beaufort 'formed alliances with members of the Network'.[102] Parry, Sabine, Fisher and Foster all functioned within this network.

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99 Owen quoted in Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, p. 166
100 Ibid, pp. 295-296
101 Bernard Lightman, 'Refashioning the Spaces of London Science: Elite Epistemes in the Nineteenth Century', in: *Geographies of Nineteenth-Century Science*, David N. Livingstone and Charles W. J. Withers, eds. (London: University of Chicago Press, 2011), p. 27
102 Lightman, 'Refashioning the Spaces of London Science', p. 28

The early nineteenth century saw the birth of new societies: The Geological Society (1807), the Astronomical Society (1820), the Geographical Society (1830) and the British Association for the Advancement of Science (1831). There were strong links between these societies and the Navy which provided good opportunities for individuals pursuing a career in science. Where in the late eighteenth century, astronomers, mathematicians and natural philosophers accompanied exploration or surveying voyages, in the early nineteenth century, naval officers themselves were taking over these duties, transforming themselves into scientific naval officers as they did so. Areas in which to work and perhaps excel included exploration of the Arctic, Africa or the Pacific, geodesy, terrestrial magnetism, tides, meteorology, astronomy and surveying. Appointments were often secured 'because of their scientific activities … [and] on the strength of their scientific records and skill in using precision instruments'.[103] Thanks to the efforts of the Hydrographic Office under Hurd, Parry and Beaufort, collection of data and growing specialisation was particularly evident in the surveying service. Since there were no specific qualifications for naval officers pursuing science at sea, the training was practical and took place on board ship.[104]

Henry Browne's basement, mentioned in the previous chapter, served as an 'informal and extremely elite private space' in which Admiralty officers were trained.[105] Many of the Arctic pioneers of the early nineteenth century were either trained, or connected to those trained there by Kater: William Edward Parry, Edward Sabine, George Fisher, Basil Hall, Frederick William Beechey, James Clark Ross, and Henry Foster. Commissioned to serve as lieutenants on the initial Arctic voyages in 1818, Kater considered that Parry and Beechey were 'fully competent to prosecute the required Observations and Experiments'.[106] Their

[103] Cock, 'Scientific Servicemen in the Royal Navy', pp. 105-106
[104] Ibid, pp. 108-109
[105] Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 109
[106] Henry Kater quoted in Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 109

training continued in the challenging conditions of the Arctic. During the John Ross expedition of 1818, Parry wrote to Kater that he would be glad 'to hear that I shall certainly have a share in all the observations on shore, as both Captain Ross and Sabine are very desirous that I should do so', adding that 'I cannot express the obligation I feel to you for the instruction you have given me respecting the instruments, of which I now feel the full practical value'.[107] Parry and Sabine established a deep respect and friendship during the six months of the expedition, described by Sabine in his journal: 'I cannot quit the subject of Hare Island without expressing how much I feel Parry's kindness in remaining with me – how greatly I am indebted for the effectual assistance he rendered me; and how much his agreeable society and conversation conduced to render these few days most happy in their course and pleasing in their recollection'.[108] Parry had already established himself in both science and teaching, during his appointment at the North American station in 1813. Here, he had studied nautical astronomy which resulted in the privately printed *Nautical Astronomy at Night,* written to instruct junior officers.[109]

For Michael Bravo, one result of John Ross's failed expedition of 1818 was a change in the social organisation of science on British voyages of discovery with increased cooperation between naval navigators and Royal Society observers.[110] The elements of these expeditions (geographical and scientific) were governed by two different bodies working in collaboration. Joseph Banks and John Barrow issued the instructions for geographical discovery whilst the Pendulum Committee oversaw the issuing and instruction for science. Bravo pointed out that on these polar expeditions, the work between the naval officer and the Royal Society observers was intrinsically related through the use of the same instruments. However, one

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[107] Letter from William Parry to Henry Kater, 1818. SPRI, GB 15: MS1467
[108] Edward Sabine, Journal and letters during Ross's expedition, 1818. PWDRO, 581/81
[109] William Edward Parry, *Nautical Astronomy by Night*, (Bath: Meyler and Son, 1816)
[110] Michael Bravo, *Science and Discovery in the Admiralty Voyages to the Arctic Regions in Search of a North-West Passage (1818-1825)*, Unpublished PhD, University of Cambridge, (1992), p. 117

crucial difference between these two groups was *how* these instruments were used. The scientific observer paid ‘great attention to calibration, consistency, accuracy in habits in the observer, and above all, repetition’, while for the naval officer, ‘expedience and speed’ mattered due to ‘limited resources and time’.[111] For the scientific observer, discipline and repetition were important for recognition and credibility of themselves and their readings. Strict hierarchal structures were embedded in naval tradition, and so the naval commander assumed absolute authority. Sabine may have been appointed and instructed by the Pendulum Committee and thus operated in accordance with the goals of the Royal Society, but on board ship, he remained under the direct authority of the commander, John Ross. Rather than subjecting Ross to Sabine’s authority, Parry was allocated the duty of assisting Sabine in the work assigned to him.[112] Although Parry and Sabine disagreed with Ross’ decision to return to England after naming the non-existent Croker Mountains, they could not undermine his authority. By appointing Parry as commander of the following expedition, and Sabine as the Royal Society observer, potential tensions were eased. Parry, therefore, can be seen as a model ‘scientific naval officer’.

Under Parry’s command, training of junior officers continued in subsequent expeditions in search of the North-West Passage. In addition to instructions received from the Admiralty, Parry specified what he expected from his officers: ‘No opportunity must be lost of making the various observations connected with Astronomy and navigation, and any officer will of course be desirous to obtain all the practice in this way he can. The sights and Calculations of each observer will be kept in different books, and every result reported to me that I may compare them with my own. I trust that we shall thus be enabled to produce on our return, such a collection of observations as may promote the interest of science, and

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[111] Bravo, *Science and Discovery in the Admiralty Voyages*, pp. 114-115
[112] Ibid, pp. 113-124

justify the high expectations formed of us'.[113] Practical experience of observing and using instruments in the field was a crucial part of training if any attempts at accuracy were expected. As one officer of the expedition wrote to his brother, 'all this is most easy in theory or on paper, but it is most difficult in practice. This earth is not a perfect sphere; the atmosphere changes the appearances and places of objects, without our being able precisely to value the changes produced; there is always some uncertainty in fixing the point where the phenomenon in question actually does take place; nor is it possible to determine with absolute precision the instant of time of its appearance'.[114] Practical guidelines and instructions were easier to write than to follow, and those isolated in the field dealt with these issues with what Miller termed 'wetware': 'embodied skills, abilities, judgements and goals'.[115] Parry, a gentleman, naval officer and part of an elite group of men of science had precisely the requirements to assume these responsibilities.

Foster was also firmly embedded in this circle of gentlemen of science, although he has been described as an anomaly in terms of how rapidly he rose through the ranks due to his exceptional scientific ability.[116] In all probability trained at Browne's place alongside Basil Hall, Foster accompanied Hall on HMS *Conway* to assist in pendulum experiments in South America. William Webster, surgeon on the *Chanticleer*, wrote that 'it was not until serving in the Conway, under Captain Basil Hall, that his [Foster's] scientific qualities were fully evinced. In addition to the employment of surveying, he was then entrusted with the use of a collection of astronomical instruments, which had been supplied to Captain Hall by the Board of Longitude. With these he made some excellent observations, which, with pendulum

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[113] Parry's instructions to officers HMS *Fury* and *Hecla*, 1821-23 and 1824-25. SPRI, GB 15: MS438/8
[114] Unknown author, *Letters Written During the Late Voyage of Discovery in the Western Arctic Sea, By an Officer of the Expedition*, (London: Printed for Sir Richard Phillips and Co., 1821), pp. 78-79
[115] Miller, 'Longitude Networks on Land and Sea', p. 224
[116] Randolph Cock, *Sir Francis Beaufort and the Co-ordination of British Scientific Activity*, *1829-55,* Unpublished PhD, University of Cambridge, (2002), p. 49

experiments, the first he ever undertook, obtained him admission into the Royal Society'.[117] Foster subsequently assisted Sabine in the Arctic on HMS *Griper* in 1823.[118] As astronomer (although nominally appointed as assistant surveyor) on Parry's third voyage, Foster 'employed the leisure afforded by an arctic winter in making some exceedingly interesting experiments on magnetism, refraction, and the velocity of sound, besides those connected with determining latitude and longitude'.[119] Foster's results were published in 1826 in the *Philosophical Transactions* and, after again escorting Parry on his attempt to reach the North Pole, Foster received the Copley Medal from the Royal Society in addition to his commander's rank. His appointment to the *Chanticleer* followed shortly thereafter. This expedition was designed 'expressly for the employment of Foster', following Hall's earlier call for an expedition devoted solely to science.[120]

Parry and Foster may well have been those Owen had in mind when he claimed that the Admiralty was 'prey to pretenders of scientific ability' interested in 'special schemes'.[121] Certainly, it is with this sentiment in mind that his comments on Foster's shipboard practices should be interpreted. In a letter to Beaufort written from HMS *Eden* in 1831, Owen reflected on a period of three weeks spent with Foster during the *Chanticleer* expedition. Foster, he wrote, 'alone does all, he observes, he compares, he notes', adding that 'those around him are in the clouds as to his work and really, altho' with him near 3 weeks, I could never get my time compared with his'.[122] His own practice, Owen continued, was

> different, I give practical lessons to those I mean to employ, I make them teach others, I never or very rarely <u>work</u> myself but I direct all, examine all, encourage, scold, and

[117] W. H. B. Webster, *Narrative of a Voyage to the Southern Atlantic Ocean in the Years 1828, 29, 30, Volume II*, London: Bentley, 1834), pp. 206-207
[118] Waring, *Thomas Young, the Board of Longitude and the Age of Reform*, p. 120
[119] Webster, *Narrative of a Voyage to the Southern Atlantic Ocean, Volume II*, p. 207
[120] Webster, *Narrative of a Voyage to the Southern Atlantic Ocean, Volume II*, p. 207; Miller, *The Royal Society of London 1800-1835*, p. 127
[121] Brown, *William Fitzwilliam Owen: Hydrographer of the African Coast*, pp. 295-296
[122] Letter from William Fitzwilliam Owen to Francis Beaufort, 'On the longitudes of certain points in South America and in the West Coast of Africa', HMS *Eden*, May, 1831. UKHO, MP 58

> above all teach that where there is mystery, suspicion necessarily follows: My work is always open, every /gentlemen/ boy in the ship is obliged to know something of it and my results are generally those of many observers whose works I have merely analysed, criticised, and adjusted and are open to every body; merchant ships, ships of war, or shore people. When I have taught others to walk I have let go of the leading strings and by encouraging and leading them to continued exercise, they soon learn to run. I have never depended on my own individual strength at all in these pursuits and they have always been mixed with so many other cases and duties that it would have been almost impossible to have given myself up to them that it was impossible must be evident since I have never with the strongest predilection for it been able to do so.[123]

Owen was certainly blowing his own trumpet here, as view this must be tempered with what some of the officers he trained thought of the process:

> Becher and Bayfield looked back on this period of their lives with mixed feelings. Owen was a hard taskmaster, and Bayfield recalled 'working after the Owen style' as an example not to be followed: 'I do not think anything is gained by exhausting the mind and body by incessant application like that, which arose from keeping everybody at work all day and nearly all night as our old friend Owen did'. Becher remembered that 'Captain Owen used to keep me up till about 2 in the morning writing long letters, which I thought very hard'.[124]

Bayfield would later write of Owen that 'he should not like to serve under him at sea' due to his 'disciplinary nature'.[125] Although this does give us insight into the training conditions on board Owen's expedition, this can also be seen as a statement concerning the credibility of practice. Owen also wanted to 'remove any impression that I am desirous to attach an immaculate character to our longitudes I must in justice to the gentlemen who served under me say that I am quite sure our measures were made with more care and that more care and attention was paid to the preservation of the chronometers, which were never suffered to be removed from their places, than I have ever seen anywhere else'.[126]

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[123] Ibid

[124] Burrow, *Captain Owen of the African Survey*, p. 62

[125] Henry Bayfield to John Harris, 20 January ,1823, Harris Letters quoted in Brown *William Fitzwilliam Owen: Hydrographer of the African Coast*, p. 75

[126] Letter from William Fitzwilliam Owen to Francis Beaufort, 'On the longitudes of certain points in South America and in the West Coast of Africa', HMS *Eden*, May, 1831. UKHO, MP 58

Owen was arguing that his method of practice lent credibility to his results, rather than his social status. In contrast, Foster could rely on his status as a scientific naval officer and a gentleman:

> There were but few officers in the service, whose minds could have been more highly cultivated than Foster's, and although he had a mild blue eye with a corresponding complexion, almost delicately fair, his features were not the less manly or intellectual. His smile and tone bespoke him every inch the gentleman; and the anxious expression of his yet more anxious mind, evinced that searching after knowledge which had so successfully identified itself with his short career. Foster, had he lived would have been a distinguished navigator; he was an excellent officer, the best nautical scholar I ever knew, and a good astronomer.[127]

It is hard not to read Owen's comments as a thinly veiled attack upon those 'pretenders of scientific ability' that he so disdained. Comparing his slow and difficult career, his continuous brushes with the Admiralty, it must have been particularly hard to meet with Foster, an officer twenty-three years his junior, whose rapid rise through the ranks led him to captain the voyage of the *Chanticleer* with fifteen of the best chronometers that the Observatory had to offer.

Inman and the Royal Naval College

Two years after the closure of the Royal Naval Academy in 1806, the Royal Naval College (RNC) opened to new students in 1808, refurbished and expanded. The governor of the College was the First Lord of the Admiralty. Successive naval captains were appointed as immediate supervisors, under the title Lieutenant Governor, and as its first and only headmaster was Professor James Inman. Inman was a skilled mathematician, having graduated at Cambridge in 1800 as Senior Wrangler. He subsequently served as astronomer on board HMS *Investigator,* where he served alongside Matthew Flinders. At the College, he

[127] 'Polar scenes', published in The Times, (Halifax Nova Scotia) circa. 1835. Probably written by Berkeley Westropp, midshipman on board HMS Fury. SPRI, GB 15: MS 1562:D

produced *Navigation and Nautical Astronomy for the Use of British Seamen,* published in 1821. New mathematical methods were introduced by Inman: the haversine and its logarithms, which simplified the calculations of spherical trigonometry, was one that he applied to the observations required for local time. Robert Fitzroy was one of several officers educated under James Inman at the Royal Naval College, often termed collegians. Bartholomew James Sulivan (1810-1890), who was also educated there and went on to become a hydrographic surveyor, wrote about his experience at the College:

> The head of studies was the Reverend Professor James Inman, D. D., author of the work on navigation, under whom were three assistant-masters for mathematics: first, Peter Mason, M. A.; second, Charles Blackburn, M. A.; and third, Mr. Livesay. The preceptor, the Rev. W. Tate, M.A., took the classical classes, history, geography, and English. French was taught by M. Creuze, a French *émigré.* We were also taught fencing and dancing. The forenoons were given to mathematics, the afternoons to French and drawing. . . there were also classes for naval architecture. . . We began geometry with Mr. Livesay; but no boy could get on unless he studied in his own cabin and at the dining-room tables in the evenings.[128]

The curriculum attempted not only to combine the theoretical with the practical, but also to provide an education befitting a gentleman. The Royal Naval College was another attempt by the Admiralty to centralise authority and control recruitment and appointments. But it also drew upon the networks established by the Royal Society and the Board of Longitude. Without an astronomer on board, Inman's manual implied 'a system whereby Royal Navy officers were tasked with regulating instruments through a system of recording which *at the same time* served so as to regulate them'.[129] This served as a mechanism by which one could trust observations made by naval officers using unreliable instruments. Phillips has argued that the aim of the RNC, with Inman as its master, was to 'draw upon the networks of timekeeper circulation that they, and the Greenwich system had helped put into motion

[128] Henry Norton Sulivan, *Life and Letters of the Late Admiral Sir Bartholomew James Sulivan*, (London: John Murray, 1896), p. 9
[129] Phillips, *Making Time Fit*, p. 208

since the early 1770s, and to impose their own kind of disciplined, principled management'.[130] If this were so, then Fitzroy would be a prime example of the naval officer that Inman produced.

Fitzroy served one of his earliest appointments, aged fourteen, on board HMS *Glendower* under Robert Cavendish Spencer, whose reputation and connections ensured that 'his ships were always crowded with young aristocrats and the sons of senior naval officers'.[131] He had joined this vessel two years after joining the Royal Naval College and was rapidly promoted to midshipman. On passing his examination with full distinction Fitzroy was promoted to lieutenant in 1824, aged nineteen. His next appointment was on board HMS *Thetis*, where Sulivan served as a midshipman. As we have seen from the above section on shore-based learning and textual instruction, we have a sense of the knowledge Fitzroy would have attained before proceeding to sea. Sulivan again provides us with insights into the continued training on board ship.

Sulivan attested how they had 'regular use of the table in the captain's fore-cabin for our working observations. We, the collegians had to take sights in the morning for the longitude, and at noon for the latitude, with occasional lunars, which we worked in the fore-cabin'.[132] Speaking of Fitzroy in particular, Sulivan wrote that he 'was one of the best officers in the service. . . [he] was one of the best practical seamen in the service, and possessed besides a fondness for every kind of observation useful in navigating a ship. He was very kind to me, offered me the use of his cabin and of his books. He advised me what to read, and

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[130] Phillips, *Making Time Fit*, p. 209

[131] John Knox Laughton, revised by Andrew Lambert, 'Sir Robert Cavendish Spencer', *Oxford Dictionary of National Biography*, (online ed.), Oxford University Press. Last accessed 16 September 2020: https://doi.org/10.1093/ref:odnb/26136

[132] Sulivan, *Life and Letters*, p. 22

encouraged me to turn to advantage what I had learned at the college by taking every kind of observation that was useful in navigation'.[133]

Fitzroy assumed command of HMS *Beagle* in 1828 when he was appointed by Admiral Sir Robert Otway, then Commander-in-Chief of the South American Station. Although following the suicide of the *Beagle's* Commander, Pringle Stokes, effective command had passed to the First Lieutenant, George Skyring, this was overruled by Otway's patronage of Fitzroy, itself underwritten by Fitzroy's aristocratic family connections.[134] Fitzroy was satisfied with the appointment, writing to his sister that it was 'not only a promotion, but employment and that of the most desirable kind, for it opens a road to credit and character, and farther advancement in the Service. Providing I do not fail in my exertions'.[135] As I showed in the previous chapter, Fitzroy's family connections and friendship with Beaufort facilitated his appointment to command the second surveying expedition of HMS *Beagle*.

The collection of papers belonging to John Lort Stokes now retained in the National Maritime Museum allow further insight into the ongoing training under Fitzroy. The papers, a collection of rough notes and fair copies of rules and examples of navigational matters, covers not only the second voyage of the *Beagle*, but also the vessel's third voyage to Australia. Stokes had joined the Royal Navy aged twelve and served as a midshipman on the first voyage of the *Beagle* where he was appointed mate. During the *Beagle*'s second voyage he served as assistant surveyor. His notes indicate that he read Owen's 'Essay on Chronometers', and commented on the method of interpolation, adding his view on what the best practice might be. As he was placed in charge of the chronometers, alongside Stebbing, it is possible he was using this directly as an instruction manual. Part of this

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133 Sulivan, *Life and Letters*, pp. 15-16
134 Harold L. Burstyn, 'If Darwin Wasn't the "Beagle's" Naturalist, Why Was He on Board?' *British Journal for the History of Science*, 8, (1975), pp. 62-69
135 Fitzroy quoted in James Taylor, *The Voyage of the Beagle*, (London: Conway, 2008), p. 48

collection also contains Stokes handwritten copy of a paper Fitzroy had written on the manner of surveying that they adopted on the *Beagle*. Stokes also copied out navigational calculations, including triangulation, dead reckoning and longitudes by chronometer. One section references Inman, where Stokes had copied out a rule that would appear to come from Inman's updated manual of 1826 (see figures 4.3 and 4.4).

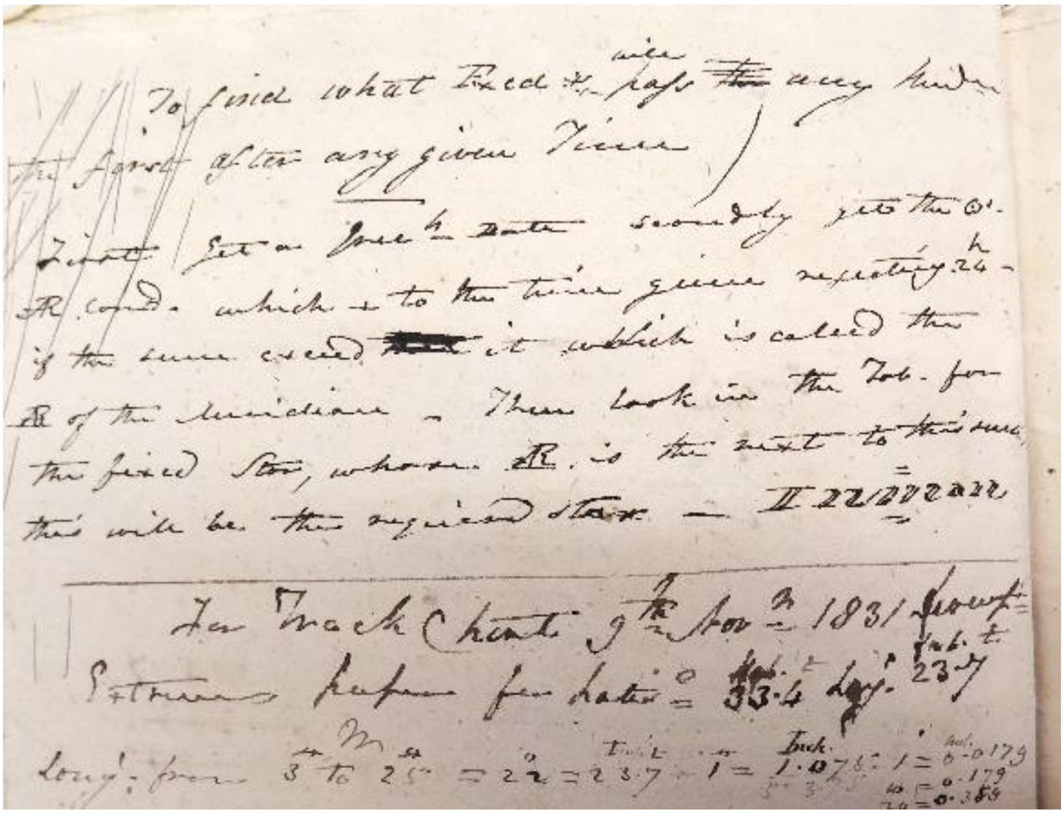


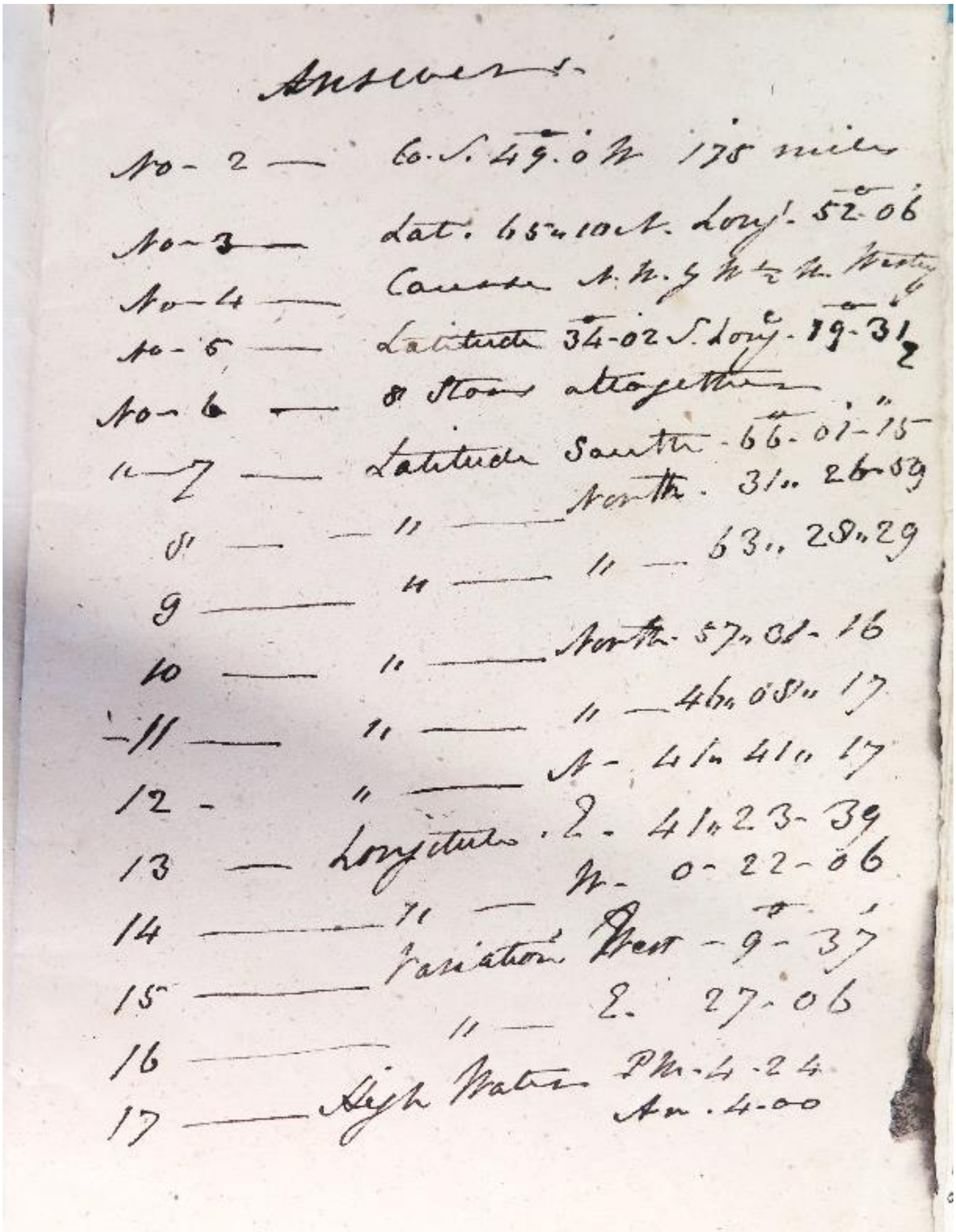
Figure 4.3: 'To Find what Fixed Star will pass any Meridian the first after any given time', Navigational notebooks, John Lort Stokes. NMM, STK/26/1

To find what Fixed Star will pass the Meridian the first after any given Time.

(209). From the ship date and longitude get a Greenwich date (195), and take out of the Nautical Almanac the sun's right ascension, which add to the ship astronomical apparent time (rejecting 24 hours if the sum be greater than 24 hours). Then look in the Table for the fixed star, whose right ascension is the next to this sum; this will be the required star.

Figure 4.4: James Inman, *A Treatise on Navigation and Nautical Astronomy*, (Portsea, 1821), p. 107

The notebook also included a page entitled ‘answers’ which bears a striking resemblance to the mock exam Inman included in his 1826 manual (see figures 4.5 and 4.6). Although from the answers, it is clearly not based on this particular example.



Answers.

No - 2 — 60. S. 49.0 W 178 miles
No - 3 — Lat. 65..10 N. Long. 52.06
No - 4 — Course N. W. by W ½ W. Westerly
No - 5 — Latitude 34-02 S. Long. 19-31½
No - 6 — 8 Stars altogether
" 7 — Latitude South - 66-01-15
North . 31.. 26-59
8 — — " — " — 63.. 28..29
9 — " — "
10 — " — North - 57.. 01-16
11 — " — " — 46.. 08.. 17
12 - " — N. 41.. 41.. 17
13 — Longitude. E. 41.. 23-39
W. 0-22-06
14 — " — Variation West - 9-37
15 — E. 27-06
16 — " —
17 — High Water PM. 4-24
AM. 4.00

Figure 4.5: Answers to navigational problems. Navigational notebooks, John Lort Stokes. NMM, STK/26/1

Answers to the above Questions.

(1). See Navigation, page 461.

(2). Answer N 41° 3′ E 354 miles.

(3). Answer 102.4 miles.

(4). Answer Lat 41° 3′ N Long 15° 32′ W.

(5).
	Sun's Decl.	
March 20 . . .	0° 10′ 1″ S	Semid 16′ 5″
March 21 . . .	0 13 40 N	Answer 79° 37′ 28″ N.

(6). Pollux and α Hydræ.

(7). Answer 42° 56′ 9″ N.

(8). Answer 52° 4′ 15″ S.

(9).
	Sun's R. A.	
March 1 . . .	$22^h\ 48^m\ 31^s.6$	Answer 37° 17′ N.
March 2 . . .	22 52 16.0	

(10). Answer N $\frac{1}{2}$ E.

(11).
	Sun's Decl.	
March 21 . .	0° 13′ 40″ N	Answer 0° 45′ W.
March 22 . .	0 37 20 N	

(12).
	Sun's Decl.	
March 21 . .	0° 13′ 40″ N	Semid 16′ 4″
March 22 . .	0 37 20 N	Answer 30° 47′$\frac{1}{2}$ W.

(13).
	Sun's Decl.	
March 5 . . .	6° 3′ 13″ S	Semid 16′ 8″
March 6 . . .	5 40 0 S	Answer 46° 51′ N.

Figure 4.6: Answers to the Questions set at the Royal Naval College in the Examination of Midshipmen, March 12, 1821. James Inman, *A Treatise on Navigation and Nautical Astronomy*, (Portsea, 1821), p. 353

Stokes was promoted to lieutenant on return to England in 1837, so it is possible that these notes relate to his training for the lieutenant's examination whilst on board the *Beagle.* Stokes also copied out new rules such as 'To find the Longitude by Lunar Observations taking into the Account the Spheroidal figure of the Earth', contrasting it to Inman's old method. Further on, we find 'Raper's Double Altitude' and 'Equation for Reducing the Errors of Observations when Single Altitudes are observed for the purpose of Rating Chronometers', and notes 'On the Employment of the signs + and – in multiplications'. Whether these notes pertain to the second or third *Beagle* voyage, they show the continued study of new methods and rules by a variety of authors.

Figure 4.7: 'Life on the ocean, representing the usual occupations of the young officers in the steerage of a British frigate at sea', by Augustus Earle, circa 1836. NMM, BHC1118

Serving under Fitzroy provided good references for later employment. Fitzroy wrote to Beaufort that Sulivan was '*up to the business completely.* He is as thorough a seaman, for his age, as I know, and he has been used to the smallest craft as well as to the largest ships. He is an *excellent* observer, calculator, and surveyor, and I may truly say that his *abilities* are better than those of *any* man who has served with *me'*.[136] Stokes had to wait longer for a promotion, not obtaining this until he had served eleven years as a mate, despite Fitzroy's attempts to promote him. Fitzroy testified to his qualities, as Stokes had been 'my assistant, by my own choice, during eight long years of rough and trying work. I know not the man I should prefer to him in a professional way, as surveyor or in a private capacity as a staunch and sensible friend. . . [by] far the greatest share of work has been done by him. Much by him Alone'.[137]

Conclusion

Basil Hall's remark with which I began this chapter was to the effect that theoretical knowledge of chronometers had a limited effect on practice and that *how* this knowledge was put to use was entirely dependent on the ship on which they found themselves, whether as a midshipman, a lieutenant, or even as captain. Textual learning was a small part of becoming a skilled navigator, chiefly amongst those who emerged in the late eighteenth century. Textual instruction acquainted officers with the theories and rules behind longitude by chronometer; experience at sea taught them how to implement them.

Scientific voyages not only provided the means for experimental testing of methods, but also served to train young officers according to the aims of the voyage. This chapter has examined only a small selection of manuals, academies and voyages. The unregulated

[136] Sulivan, *Life and Letters,* p. 49, original emphasis
[137] Certificates of service in *BEAGLE,* 1831-36, signed by Fitzroy, 17 Nov 1836, with addition in Fitzroy's hand testifying to Stokes' qualities. NMM, STK/29, original emphasis

pathway of the general naval officers reveals that shipboard practice still remained the dominant element in the construction of a naval officer. The end of the Napoleonic Wars saw a change in direction of the Royal Navy, where scientific ability would more likely lead to a distinguished career. This had a profound effect on how officers were trained. Owen was moulded too firmly in the tradition of the 'old navy' of the eighteenth century to adapt to this new reality. Bravo's distinction between the naval officer for whom expedience and speed mattered more than accuracy and consistency would apply to Owen, while Parry, Foster and Fitzroy embodied those officers who paid 'great attention to calibration, consistency, accuracy in habits in the observer, and above all, repetition'.[138]

An essential, and often overlooked point in the history of the chronometer, is how intrinsically linked the chronometer and its use were to astronomical methods. As I have shown, early chronometric instruction focused predominantly on explaining the astronomical terms which formed the basis for longitude determinations, whether these were made chronometrically or astronomically. This is clearly evident in the lunar instructions, which in the late eighteenth century included the basic knowledge required for longitude by chronometer. Those equipped with the best chronometers were not only well-connected gentlemen, but also those who excelled in astronomical navigation. As contemporary commentators remarked, officers were often lacking in these basic astronomical and mathematical skills.

The chapters following examine a broader range of archival sources to examine how the social context of these officers was reflected in their navigational practices on board ship. Wynne has examined 'technologies as rule-following behaviour, arguing that emerging practices define "rules", rather than rules controlling practices'.[139] The rules that emerged

[138] Bravo, *Science and Discovery in the Admiralty Voyages*, pp. 114-115
[139] Brian Wynne, 'Unruly Technology: Practical Rules, Impractical Discourses and Public Understanding', *Social Studies of Science*, 18, (1988), p. 147

from the experimental practices on board these voyages are a theme examined in the remainder of this thesis. What is relevant to note here is the impact of textual instruction, early education and subsequent training on board ship.

Navigational manuals were numerous and increasingly detailed in their content throughout the late eighteenth and early nineteenth centuries. Whether a young boy studied on board ship or at a naval college, they formed the basis for their initial introduction to navigation. Textual instruction in chronometry was limited before it gradually became more common from about 1810. This therefore does not tell us much about how practices were established on different vessels. What is clear, however, is that those officers issued with chronometers used them for different purposes. The 'scientifically' minded officer paid attention to repeated observations, accuracy, recordkeeping and precision. As a surveyor, Owen was equipped with 'lesser' chronometers (see chapter 3) to survey the East African Coast, and had less time and resources to pursue astronomical practices as were performed during the Arctic expeditions. *What* was required of the chronometer therefore informed *how* it was used. This relationship would define how the chronometer interacted with, and was situated within other practices, whether navigational, geographical or scientific in nature. With this evidence in mind, the following chapter examines what officers did with the instruments once they received them on board ship.

5

The Care and Management of Chronometers at Sea

> This arises almost entirely from the peculiar nature of the instrument in question, & this argument therefore applies exclusively to chronometers, & not at all to sextants or other nautical instruments. These peculiarities are, - that the merits of no chronometer can be judged of at sight, but require a considerable period of patient & careful trial before any safe opinion can be pronounced upon them.[1]

Introduction

Captain Basil Hall's comment above was made in relation to the purchase of chronometers, yet the same sentiment applied equally to the use of instruments on board ship: that only with their use could instruments be pronounced effective and reliable, or otherwise. In May 1819, William Edward Parry set off on his Arctic explorations on his first command with ten of the best chronometers then available. Edward Sabine was familiar with some of the chronometers supplied by instrument makers Arnold and Earnshaw as they had been previously employed on board the *Isabella.* London clockmakers, Parkinson and Frodsham, also lent three of their chronometers for this voyage, each of which had their temperature compensation specifically adapted for the Arctic climate. Sabine trialled and rated the chronometers in the stable temperature of Henry Browne's basement. By the time of departure Parry had the chronometers 'an excellent & superior assortment … nicely arranged in my cabin, and everything perfectly to rights'.[2]

It is misleading, however, to assume that these specially selected chronometers in the hands of these experienced observers automatically produced reliable data. The proliferation

[1] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956
[2] William Parry to his parents, HMS *Hecla* at the Nore, 9 May, 1819. SPRI, GB 15: MS438/26/46

of 'instructions' supplied to officers and travellers in the nineteenth century demonstrate that naval authorities and scientific societies increasingly required the disciplining and regulating of those using instruments.[3] This is why, in 1827, Richard Owen published his 'Essay on Chronometers', given that in his view, 'no sufficient rules for the management and use of them at present exist by which the best and surest results may be obtained' which were required 'to detect and guard against their wanderings' to which they were liable.[4] Owen recognised that the problem also had to do with experience, as his publication was intended 'to instruct seamen … not to inform the Astronomer'.[5]

Numerous studies have shown the problems that occurred with instruments used in the field.[6] It was through dealing with these issues that ideas about the instruments were formed and from these ideas that experienced users would offer their views on best, or at least adequate, practice. Instruction in chronometry gradually expanded to include these experiences following the voyages of the early nineteenth century.

This chapter examines the particular issues that users faced, whether general or unique to specific circumstances, and how these informed the practices that evolved. The first section of the chapter examines how the instruments themselves were physically

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[3] For example: Felix Driver, 'Distance and Disturbance: Travel, Exploration and Knowledge in the Nineteenth Century', *Transactions of the Royal Historical Society,* 14, (2004), pp. 73-92; Jane Amanda Wess, *The Role of Instruments in Exploration: A Study of the Royal Geographical Society 1830-1930,* Unpublished PhD, University of Edinburgh, (2017); Simon Naylor, 'Weather Instruments all at Sea: Meteorology and the Royal Navy in the Nineteenth Century', in *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Routledge, 2016), pp. 77-96

[4] Richard Owen, 'An Essay on the Management and Use of Chronometers', in: *Tables of Latitude, and Longitudes by Chronometer*, William Fitzwilliam Owen, (London; Duckworth and Ireland, 1827), p. 3

[5] Ibid, p.3

[6] Charles W. J. Withers, 'Geography and "Thing-Knowledge": Instrument Epistemology, Failure, and Narratives of 19th-Century Exploration', *Transactions of the Institute of British Geographers,* 44, (2019), pp. 676-691; Matthew Goodman, 'Proving Instruments Credible in the Early Nineteenth Century: The British Magnetic Survey and Site-Specific Experimentation', *Notes and Records of the Royal Society*, 70, (2016), pp. 1–18; Simon Schaffer, 'Easily Cracked: Scientific Instruments in States of Disrepair', *Isis*, 102, (2011), pp. 706–717; Alexi Baker, '"Precision", "Perfection" and the Reality of British Scientific Instruments on the Move During the 18th Century', *Material Culture Review*, 74-75, (2012), pp. 14-29

managed to withstand the difficulties of travel. This involved protecting them from variation in temperature, shocks, movement and the effects of magnetism. Despite these precautions, users still experienced a variety of problems with their instruments as I shall show. These practices were therefore constantly evaluated and adapted from the problems experienced, as despite the best of care, many instruments ceased to work properly. The second section examines what went wrong at sea and how users dealt with instrumental failure. As I show, instruments slipped between varying states of disrepair, ranging from suspect to unreliable to totally useless. Nevertheless, users adapted and adopted their working practices accordingly.

For instruments to function adequately, more than just careful management of the instrument itself was required. Their human operatives required regulating too. The final section examines how users were trained and regulated. It is important to understand, even to emphasise, the need to prevent human error whilst handling, winding and comparing instruments of navigation at sea. Authors writing instructions on chronometry in navigation manuals entirely overlooked these specific parts of practice, until and unless they were addressed by those with experience in the field. The issues were, as I shall show, problematic enough to warrant attention and guidance.

Recent research has studied the problems of explorers and surveyors replicating knowledge making activities across the globe using astronomical, mathematical and natural philosophical instruments. Compasses, dip needles, sextants, artificial horizons, astronomical clocks, transit instruments and chronometers all faced limitations even as they were essential devices for the undertaking. As Goodman has noted, ‘travel was both essential for, and detrimental to, the science of terrestrial magnetism’ and the same applied to the chronometer.[7]

[7] Goodman, ‘Proving Instruments Credible’, p. 255

Portability or the ability of these instruments to work at a distance, away from sites of authority and expertise, 'in the hands of others', was a key problem.[8] Portability was more than just transportation from one location to another, as some of these instruments had to perform in transit. Conditions varied and could be stringent; the pitching and rolling of ships, extreme climates, high humidity and constant temperature fluctuations. Initially movement was condemned as it was considered to have a negative impact on chronometers, although later in the century increasing number of users felt that temperature variations, not movement, were the more significant cause of irregularities. These beliefs underwrote how proper management was defined. Correct management of chronometers was still in its experimental stages in the early nineteenth century, hence the lack of textual instructions. Instrument makers, astronomers and users were all aware that internal and external factors affected the regular going of the instrument but not all agreed to what extent this was the case and, in some cases, how much it even mattered.

Depending on the social circles they inhabited and the journals they accessed (or the astronomers they worked with), officers supplied with chronometers may have been aware of the ongoing debates concerning magnetism and its potential effects on chronometers. Depending on whose authority they relied on for information, they may have believed it was proper to transport a chronometer on shore to rate it, or they may have been of the view that once settled on board the less the chronometer was handled the better. Some vessels may have been fitted with a specially-made contraption for holding chronometers; others were housed in an empty drawer or convenient space on a shelf. Officers who bought their chronometers directly from the maker may have fastened it directly in place, on a shelf in a

[8] Eugene Rae, Catherine Souch and Charles W. J. Withers, ''Instruments in the Hands of Others': The Life and Liveliness of Instruments of British Geographical Exploration, *c.*1860-.1930', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), pp. 139-159

cabin. Some may have been aware that there were debates over whether or not vibrations of the deck would influence their timekeeping abilities, or that in certain parts of the ship chronometers may be less affected by the ship's motion. Most would have been aware that the chronometers should be wound at the same time each day, as was the case for determining error and rate, unless one did not mind the additional steps involving interpolation. What is clear is that there was no agreement on how the chronometers should be cared for at sea. With no specific set of instructions, how the instruments were managed varied from ship to ship and person to person. Issues in the management of chronometers at sea emerged from the practical experience of those using them and, crucially, depended upon what the users expected of them. Early-nineteenth-century chronometry was as I shall show characterised by experimental use where officers were testing the capabilities of the instruments and what they could achieve with them, and, at the same time, testing their own capabilities and expertise.

Managing chronometers

One consensus in the navigational manuals in circulation was that chronometers were fragile and unreliable. As I showed in the previous chapter, all authors noted the irregularity of chronometers as a key issue preventing their widespread use. Additional concerns were their susceptibility to temperature variations and their liability to accidental damage. Other issues arose from their use at sea. Five decades of chronometer use had proved that chronometers were a valuable navigational aid, while at the same time, users were increasingly aware of internal and external factors influencing their rate of going. Temperature, magnetism, movement, careless handling, the atmosphere of the Gulf Stream, and even the Harmattan winds, were all aspects that different users perceived to some degree affected the mechanisms of these instruments.[9] Careful management could to some degree mitigate a number of these external factors. This was a two-fold operation: careful management of the instruments themselves, but also extending to the careful management and interpretation of the data which chronometers produced (the subject of the chapters following).

Suspension

It was important to know the details of the management of the chronometers if users were to prove the credibility of the results obtained. Detailed records made during a voyage proved that chronometer users understood the unreliable nature of their instruments and were capable of managing this uncertainty. Sabine gave an account of the management of his chronometers in the appendix to Parry's *Narrative of a Voyage*. Five weeks prior to Parry's first voyage, Sabine received six box chronometers supplied by the government and three supplied by individuals in order to ascertain their reliability and determine their rates. A steam vessel then transported Sabine and the chronometers from Somerset House on 7 May 1819, which arrived at the Nore on 8 May: 'immediately after we anchored, the Bee Tender came alongside with the chronometers, and the different nautical, astronomical, and meteorological instruments, &c. supplied for the expedition. […] Besides the instruments provided by government, most of the officers have some of their own'.[10] After receiving the chronometers on board, they were placed in the same manner as the chronometers from the previous expedition under Captain Ross, with the overall intention of minimizing shocks from the ice:

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[9] James Rennell to Edward Sabine, 17 June, 1822. Correspondence of Sir Edward Sabine, PRS. RS, MS/259

[10] Alexander Fisher, *A Journal of a Voyage of Discovery to the Arctic Regions in His Majesty's Ships* Hecla *and* Griper *in the Years 1819 & 1820,* (London: Printed for Longman, Hurst, Rees, Orme, and Brown, 1821), p. 5; William Edward Parry, *Journal of a Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific Performed in the Years 1819-20, in His Majesty's Ships* Hecla *and* Griper, (London: John Murray, 1821), Appendix, p. v

> The box chronometers (with the exception of 286, for the first five weeks) were suspended from the beams of the deck in the after-cabin, in canvass cots lined with green baize. Steel springs had been furnished by Messrs. Parkinson and Frodsham, to be attached, instead of beckets, to the eyes of the cot-clews, with a view to take off the effect of jars which the ship might receive when navigating amongst ice; but the springs giving way in one or two instances, (fortunately, however, without injurious consequences) and the suspension by the eyes of the clews, or by very short beckets, appearing in other respects preferable, the springs were removed. The motion of some of the larger chronometers was checked by pulleys attached to the sides of their cots.[11]

This related to the box chronometers; pocket chronometer P&F 253 was worn constantly in a pocket and Arnold 2109 occasionally.

Henry Constantine Jennings, inventor of an insulating compass trialled on Ross's previous Arctic voyage, had supplied F&N 286 with a special mounting system for holding the instrument. The suspended contraption was formed of 'a copper cylinder upwards of a foot in length, and an inch and a half diameter, closed at the bottom, and surmounted by a basin of sufficient capacity to receive the chronometer box. The basin was suspended in gimbals by lanyards from the deck, and a small quantity of mercury poured into the copper cylinder. To the bottom of the chronometer box was affixed a cylindrical wooden leg of rather less diameter than the copper tube, into which it entered, resting on the mercury, and bearing the weight of the chronometer'.[12] Despite such elaborate attempts to minimise the effect of motion and shocks at sea, the motion was 'more lively than by the cots' with the result that the chronometer collided against the framework: although the chronometer continued to perform steadily, it stopped during 'considerable motion' of the ship.[13] It was then placed in a cot like the other chronometers but it stopped on two additional occasions. Eventually, this chronometer was set in motion but it did not manage to maintain its earlier regularity. On return, after examination by its makers, it transpired the reason for its stoppage may not have been entirely due to Jennings' suspension: rust was found on the element intended to

[11] Parry, *Journal of a Voyage,* Appendix, p. iv
[12] Ibid, p. iv
[13] Ibid, p. iv

indicate how many days had passed since winding the chronometer.[14] Parkinson and Frodsham experimented with steel springs as a suspension method, but these gave way early in the voyage and, following this failure, the same suspension as the others was adopted.

Throughout the summer months the ships found themselves navigating through ice floes, adding additional shocks to the pitching and rolling movement of the vessel. Parry described how the ship had 'received many severe blows from the ice', with the result that 'the concussions which the chronometers experienced were, perhaps, such as few of this kind had ever before been exposed to'.[15]

Figure 5.1: Situation of HMS *Hecla* & *Griper,* July 4th, 1819. Parry, *Journal of a Voyage 1819-1820*, p. 17

[14] Parry, *Journal of a Voyage 1819-1820*, Appendix, p. xii
[15] Parry, *Journal of a Voyage 1819-1820*, p. 22

Parry continued the practice of suspending chronometers in slings on the subsequent voyages of 1821-23 and 1824-25, although omitting the steel springs that Parkinson and Frodsham had devised. Pocket chronometer Arnold 14 was kept in the pocket constantly for observations whilst P&F 2109 ‘was placed in a vertical position against the ship's side, for the sake of convenient comparison to the officers in making their observations, and to prevent the necessity of taking down any of the watches except for the noon-comparison, an account of which was daily hung up for reference’.[16] To avoid further movement of the device, Parry issued additional orders during the second and third voyages: ‘It being desirable to avoid as much as possible the moving the chronometers from the place where they hang, it is my direction, that whenever the officers wish to take sights for them, they compare their watches with the pocket chronometer which is fixed in a conspicuous part of my cabin. The daily comparison of this chronometer with the rest will be found hanging up by the pocket watch’.[17]

This evidence suggests that the practice of suspending chronometers in slings was particular, but not exclusive, to the Arctic expeditions. Following his service with Parry, George Francis Lyon commanded his own Arctic expedition, in HMS *Griper,* in 1824. Lyon wrote that the shocks the ship received from the ice were particularly heavy and that the chronometers ‘were badly shaken, and in any rough weather their cots would frequently strike the beams’, indicating that these, too, were slung from the upper deck.[18] Another report specified the use of suspension: in 1827 Master of HMS *Druid* (employed in the West

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[16] William Edward Parry, *Appendix to Captain Parry’s Second Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific, performed in His Majesty’s Ships* Fury *and* Hecla *1821-22-23*, (London: John Murray, 1825), p. 4
[17] William Edward Parry’s Orders and Regulations His Majesty’s Ship Fury, 8 May, 1821, SPRI, GB 15: MS 438/8
[18] Captain G. F. Lyon, *A Brief Narrative of an Unsuccessful Attempt to Reach Repulse Bay: Through Sir Thomas Rowe's ‘Welcome’, in His Majesty's ship* Griper*, in the Year MDCCCXXIV*, (London: John Murray, 1824), p. 143

Indies) reported that the chronometer had stopped after it dropped when its suspension gave way.[19] It had fallen down 'about the height of 18 inches, in consequence of the stock that it was suspended to, having given way within the wood … the chronometer has hung in the Captain's Cabin under the Centinels [sic] eye, & to the same hook upwards of one year'.[20]

It is hardly surprising, therefore, to find the following description of the chronometers in Foster's account of them on the *Chanticleer*: 'They were put on board the Chanticleer in Portsmouth Harbour on the 21st of April 1828, and being placed in small canvas cots, lined with baize, were suspended from the deck in my own cabin'.[21] Owen described this arrangement following his encounter with Foster in 1831: 'Captain Foster has been equipped most nobly and he is a Hercules in astronomical and mechanical labor, but I fancy I see objections in his practice; his science is beyond my praise, so also are his zeal and perseverance, but his chronometers are suspended from the working deck, each in a separate cot into which they fit quite tight; the process of winding and comparing daily subjects them to much irregular movement'.[22] Following Foster's death, Tiarks was appointed to go over the observations. Just like Owen, Tiarks found fault with the way the chronometers were kept:

> the chronometers do not seem to have retained their rates for any length of time, but some of them have repeatedly altered to a considerable amount in very short intervals. As these chronometers were all considered to be very excellent ones, I am inclined to believe that Captain Owen is right in finding fault with the manner in which the chronometers were suspended from the deck of the *Chanticleer*. My own experience, as far as it goes, likewise proves that a suspension from the upper deck of a vessel is not favourable to the regular going of timepieces.[23]

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[19] Letter concerning an accident which happened to a chronometer issued to HMS *Druid*, 25 September, 1827. CUL, RGO 5/230, f. 45r

[20] Copy of a report from James Henderson, Master of HMS *Druid*, concerning an accident to the ship's chronometer, 12 May, 1827. CUL, RGO 5/230, f. 46r

[21] Henry Foster, 'Memoir of the meridian distances measured in his majesty's sloop Chanticleer in the course of her voyage to the Brazils: 1828', Astronomical Observations, HMS *Chanticleer*, 1828-31. UKHO, AO32: SFD7/7/1/7

[22] William Fitzwilliam Owen to Francis Beaufort, HMS *Eden*, May, 1831. UKHO, MP58

[23] John Lewis Tiarks, 'Dr. Tiarks's Report on Captain Foster's Chronometrical Observations', in: *Narrative of a Voyage to the Southern Atlantic Ocean, in the Years 1828, 29, 30, performed in H. M. Sloop* Chanticleer*, Volume II*, W. H. B. Webster, (London; Richard Bentley, 1834), p. 226

Chronometer tables and sawdust

The question of how best to install the instruments on board ship was evidently a matter of concern and ongoing debate. Richard Owen was clear that he thought suspension was detrimental to the going of chronometers. He opposed any construction for 'slinging' the chronometers, as they were 'liable to receive a vibratory motion that may affect their balance-wheel' and rather than limiting the effects, the slings actually exposed them to shocks.[24] Another objection lay in the additional motion caused by taking them down for winding and comparison. What was also 'very objectionable', according to Richard Owen, was the practice of keeping chronometers in drawers, as the opening and closing would 'derange' them.[25]

> The most unobjectionable method appears to be, that of having a table hung on gimbols (sic), with a weight of from 20 to 50 lbs. suspended underneath, in the manner of an Azimuth compass, so that the centre of gravity be as near the centre of its motion as possible, to permit it to keep its level permanently without being subject to vibrate, and the axes of the gimbols working in smooth stuffed leather sockets, bearing against springs in every direction, these springs being neither too stiff, nor too sensible for the weight they are to support. The pillars, or stand for the sockets, to be a fixture in the deck. Such a contrivance would go far to prevent the ill effects of the ship's motion, or concussion from firing guns, &c. The Chronometers to be placed in small partitions on the table, and to be wedged securely in their places by soft cushions.[26]

If this was not practical, the next best solution was a table fixed to the deck, through 'unconnected with the adjacent bulk-heads', with similar partitions in which to place the chronometers.[27] The best location for the chronometer depended on the type of ship. In all cases, the optimal position was as near to the centre of motion as possible but not on the same deck as the guns and cables. Richard Owen recommended the best location for

[24] Owen, 'An Essay on the Management and Use of Chronometers', p. 6
[25] Ibid, p. 6
[26] Ibid, p. 6
[27] Ibid, p. 6

chronometers for certain types of ship. His advice related to battleships ('the cockpit, with the table secured to the orlop deck'); frigates ('the lower deck, rather than the master's cabin where they are often kept'); deep-waisted vessels (in the 'fore part of the captain's cabin') and merchant vessels (where the chronometer was to be housed in the master's cabin, 'a midships, and as far forward as possible').[28] It is important to note that his *Essay* was written as a guide to best practice, and it does not necessarily reflect how the instruments were actually installed on board the *Leven* and *Barracouta,* as no evidence remains of their actual practice.

Special contraptions designed for chronometers such as Richard Owen described and Jennings provided were in all probability more common than the scant evidence suggests. Although none of these devices has survived, occasional descriptions, a drawing and an Admiralty order have. Lieutenant Thomas Phipps, late acting commander of HMS *Fly*, wrote to the Admiralty regarding the lack of regulations concerning chronometers at sea in 1824:

> there is no regular uniform system for the care and preservation at sea, of that most useful and valuable instrument the chronometer; but that almost every captain, or master, has a peculiar plan of his own, each differing from the other, and rather adapted with a consideration to the convenience of *stowage*, than towards the *preservation* of the instrument; some keeping it screwed fast down to the lockers, which is the plan recommended by chronometer-makers, having great faith in the efficacy of their *padding*, which, although good, in *addition* to other precautions, cannot alone, (however elastic) effectually counteract the violent shocks and concussions received by a ship, in a gale of wind, firing of salutes, &c. as well as other causalities and accidents to which it must be liable, fastened down in an exposed situation: others keep them locked up in a drawer, the opening and shutting of which, every time the chronometer is wanted to be looked at, must, in addition to all the above inconveniences, tend to its injury: some keep them on swinging tables, suspended from the beams, which, however preferable to the other modes, is still liable to receive continual concussions from the deck above.[29]

Phipps proposed an 'apparatus for the preservation of chronometers' in a printed pamphlet sent with his letter. According to his plan, the chronometers should be placed in a canvas cot,

[28] Owen, 'An Essay on the Management and Use of Chronometers', p. 5

[29] Thomas Phipps to John Barrow, 11 June, 1824. TNA, ADM1/3083

upon a platform of steel springs, and surrounded by a tin-reservoir filled with three gallons of hot or cold water. The whole would be placed inside a cradle, in turn attached by gimbals to an outer frame. This outer frame would in turn be set in gimbals within an outside stand composed of wood, cast iron or brass and fastened to the deck. The latter set of gimbals would counteract the 'fore and aft motion' of the ship, the former the 'athwart-ship motion'. The point of the apparatus was clear: to minimise the effects of the motion of the ship and to minimise or eliminate the effects of temperature. For Phipps, it was evident that the effects of motion and temperature variations were detrimental to chronometers and could be counteracted by this apparatus. Barrow referred the plan to Pond for his opinion, but what Pond thought and whether the plan was adopted remains unknown.

A similar plan, although lacking a temperature compensation reservoir, was proposed by Commander Edward Belcher in 1830. His plan was designed to minimise the influence from the motion of the vessel. Rather than a description, Belcher provided a detailed sketch of his contraption (figures 5.2 and 5.3).

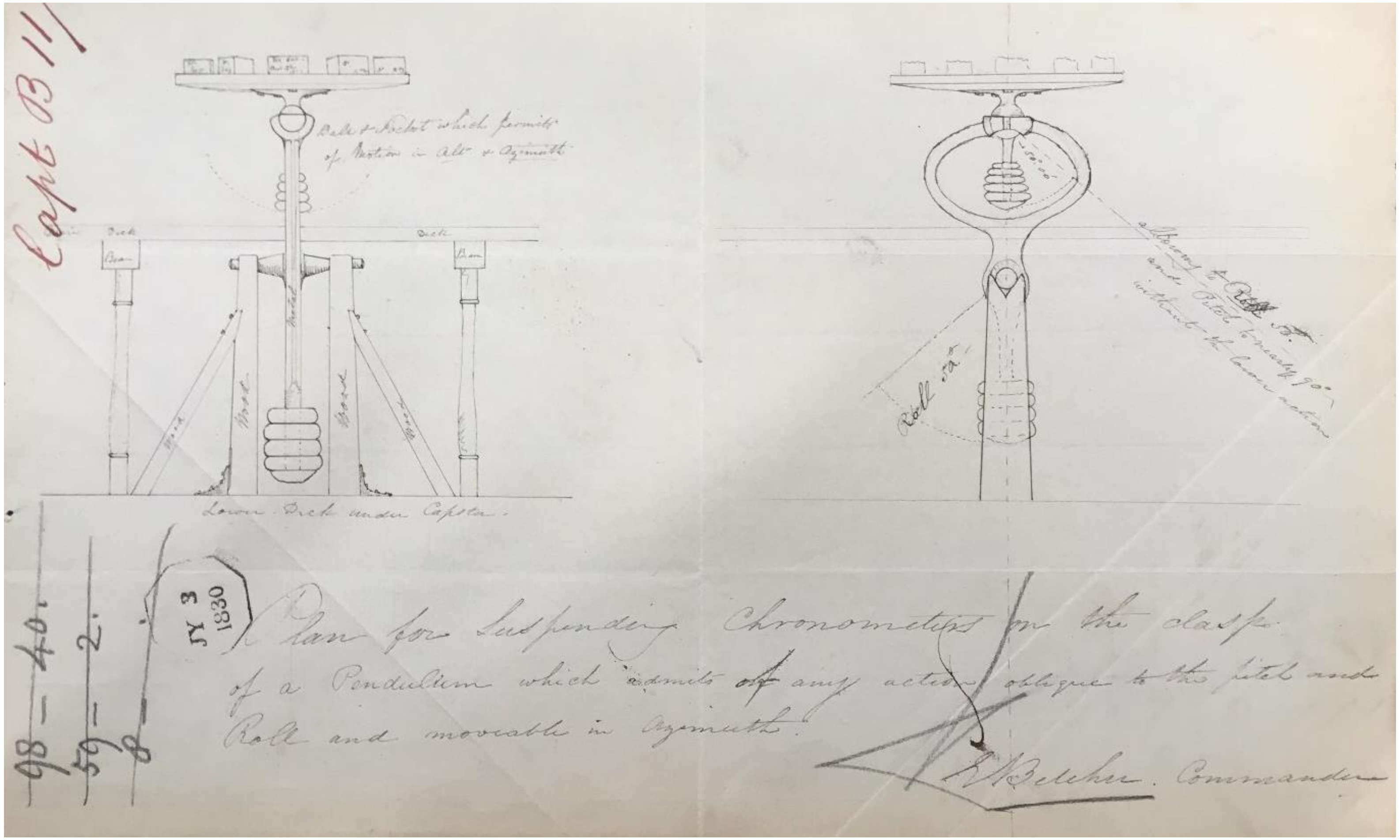

Figure 5.2: Belcher's 'Plan for suspending chronometers on the clasp of a Pendulum which admits of any motion oblique to the pitch and Roll and movable in azimuth', 1830, TNA, ADM1/1578

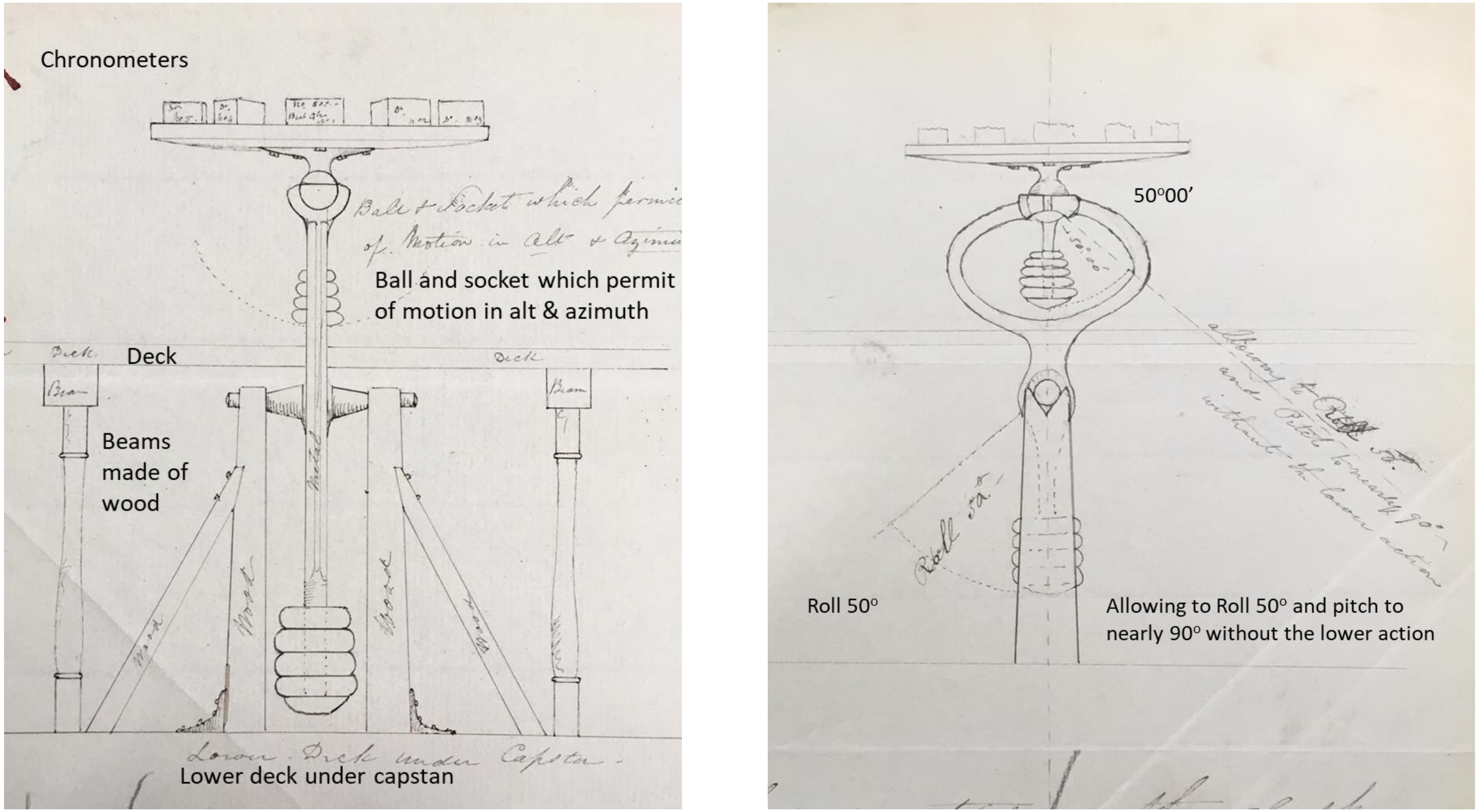

Figure 5.3: Details of Belcher's plan. Left: front view; right: side view. TNA, ADM1/1578.

Barrow subsequently ordered the Navy Board to have 'chronometer stands ... fitted in all surveying vessels according to this plan, & to be made of metal not iron'.[30] This brings into focus the debate surrounding magnetism and its effect on chronometers. Using iron for his design indicates that Belcher did not consider this to be an issue, but Barrow clearly did.

In a letter to Beaufort, Richard Owen commented on the chronometer table that had been fitted on HMS *Blossom.* Although originally an 18-gun sloop-of-war, HMS *Blossom* was fitted as a survey ship in Woolwich in 1829, before proceeding to the Jamaica Station under the command of Richard Owen. He found that 'the Chronometer House and Table answers to admiration we had some rather heavy weather between the Nore and the Downs, with the wind strong from NNE and I put a wine glass full of water on the edge of the table, which remained perfectly horizontal'.[31]

To conclude with a final example as described in the *Nautical Magazine* of 1836: 'This table was in use on board the Jackdaw, commanded by Lieut. Barnett, from the time of her sailing from England till she was wrecked on Old Providence; and has since been fitted in the Lark, which vessel replaced the Jackdaw. It has answered fully the purpose intended'.[32] The Jackdaw's chronometer table even took the chronometers out of their boxes, using their gimbals to secure them in the table (figure 5.4). Lieutenant Edward Barnett had spent three years at the Hydrographic Office between 1830 and 1833, at the time Barrow ordered all surveying vessels to be fitted with the device.

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[30] Edward Belcher to the Admiralty, 2 July, 1830. TNA, ADM1/1578
[31] Richard Owen to Beaufort, Spithead, 2 September, 1829. UKHO, LP31
[32] 'Description of the Chronometer-Table on board of H. M. Schooner Jackdaw', *The Nautical Magazine Volume V for 1836*, (1836), p. 342

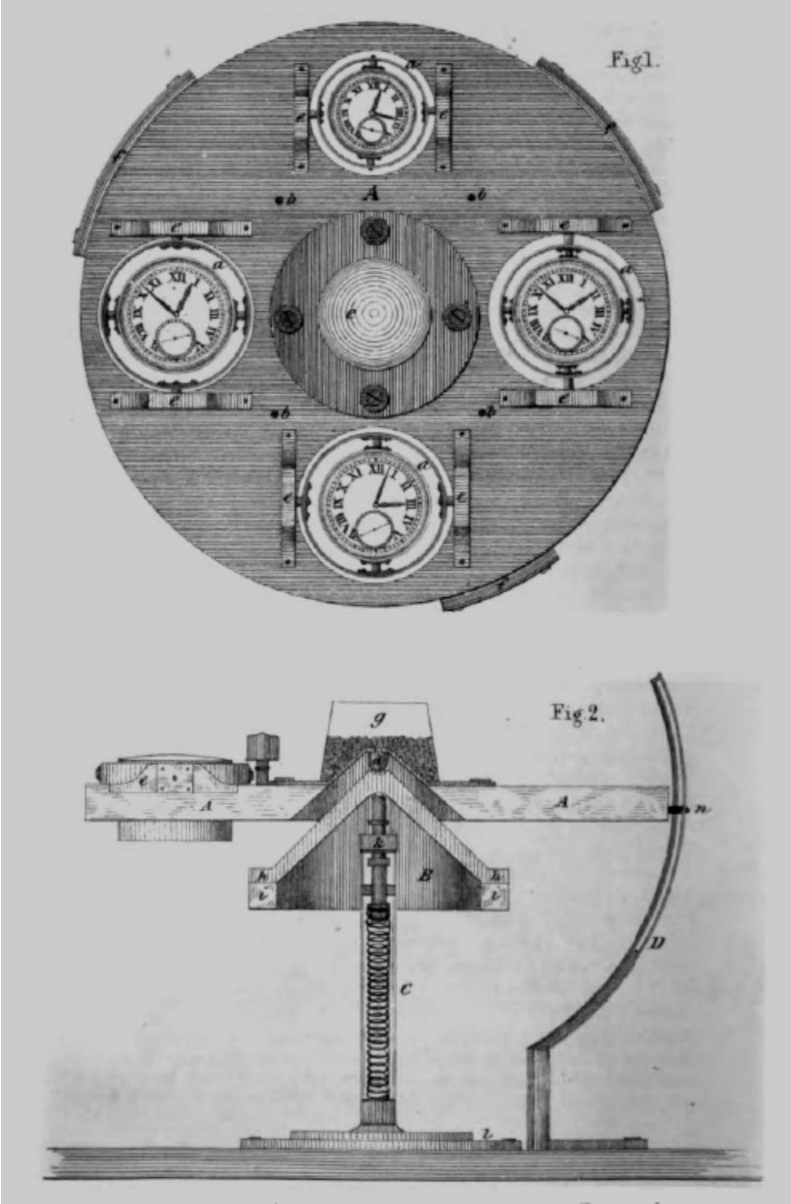

Figure 5.4: Description of the Chronometer-Table on board of H. M. Schooner *Jackdaw*. *The Nautical Magazine*, vol. 5, (1836), p. 340

Fitzroy had the benefit of assessing multiple solutions to this particular aspect of chronometer management and tables were evidently in use when he departed on the *Beagle's* second voyage in 1831. Previously, during his command of the first voyage of the *Beagle* he was able to evaluate the arrangements on the *Adventure,* and also those on the *Chanticleer,* having met with Foster at Martin's Cove at Cape Horn in April 1829. Fitzroy found that 'suspending chronometers, as on board the Chanticleer, not only alters their rate, but makes them go less regularly; and when fixed to a solid substance, as on board the Adventure, they feel vibrations caused by people running on the decks, by shocks, or by a chain cable running out'.[33] As is evident from the Stokes' archival material, the *Beagle* also carried a copy of Owen's recommendations. Based on these experiences, Fitzroy adopted the following approach:

> Suspended in gimbals, as usual, within a wooden box, each was placed in sawdust, divided and retained by partitions, upon one of two wide shelves. The sawdust was about three inches thick below, as well as at the sides of each box, and formed a bed for it which rose rather above the centre of gravity of the box and watch; so that they could not be displaced unless the ship were upset. The shelves, on which the sawdust and boxes were thus secured, were between decks, low down, and as near the vessel's centre of motion as could be contrived. Placed in this manner, neither the running of men upon deck, nor firing guns, nor the running out of chain-cables, caused the slightest vibration in the chronometers, as I often proved by scattering powder upon their glasses and watching it with a magnifying glass, while the vessel herself was vibrating to some jar or shock. All the watches were in one small cabin, into which no person entered, except to compare or wind them, and in which nothing else was kept. The greater number were never moved from their first places, after being secured there in 1831, until finally landed at Greenwich in 1836.[34]

Carrying up to twenty-two chronometers was exceptional and it would have been challenging to build a chronometer table to support that many instruments, particularly in a vessel the size of the *Beagle*. This was not an option for Fitzroy. Although plans made for the *Beagle's* conversion to a survey ship do not survive, research carried out to enable a reconstruction of the *Beagle* has indicated the layout and so specified where the 'chronometer room' was located (figure 5.5). It is clear that the instruments did not take up too much space in the manner that they were fitted.

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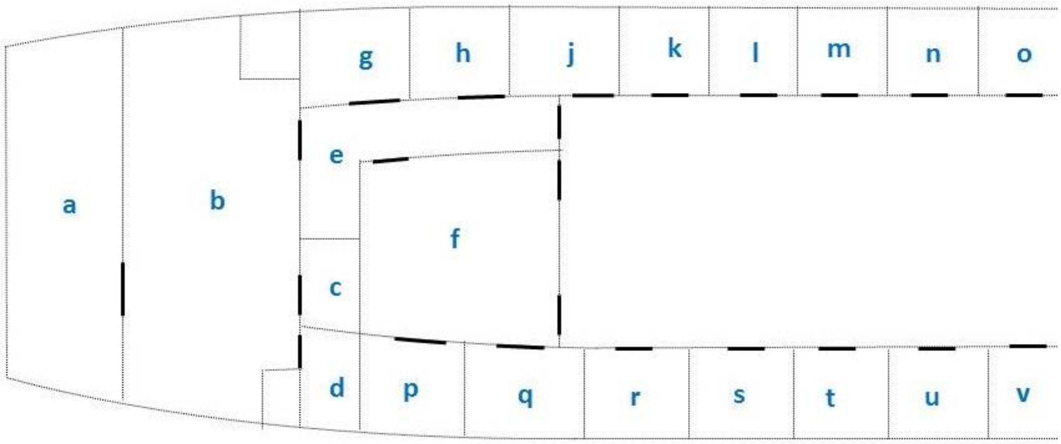
[33] Robert Fitzroy, *Narrative of the Surveying Voyages of His Majesty's Ships* Adventure *and* Beagle*, between the years 1826 and 1836, Appendix to Volume II*, (London: Henry Colburn, 1839), pp. 326-327
[34] Fitzroy, *Appendix to Volume II*, p. 326



a = Captain’s store room
b = Captain’s cabin
c = Chronometer room
d = Captain’s washroom
e = Passage and companion way
f = Messroom or Gunroom
g = First Lieutenant’s cabin
h = Master’s cabin
j = Assistant surgeon’s cabin
k = Slop’s store room
l = Captain’s steward’s pantry
m = Dispensary
n = Messroom kitchen
o = Mess Steward’s pantry
p = Second Lieutenant’s cabin
q = Surgeon’s cabin
r = Purser’s cabin
s = Midshipmen’s berth
t = Carpenter’s cabin
u = Gunner’s cabin
v = Boatswain’s cabin

Figure 5.5: Layout of the lower deck of HMS Beagle based on reconstruction plans in: Karl Heinz Marquardt, *HMS* Beagle: *Survey Ship Extraordinary (Anatomy of the Ship)*, (London: Conway Maritime Press, 1998), pp. 80-81

On the *Beagle*, chronometry was evidently an officer’s pursuit, as access to the chronometers was limited to those who walked the quarterdeck. The same has been shown on Parry’s voyages, where Parry suspended the chronometers in his own cabin and Foster likewise put them in his cabin on board the *Chanticleer*.

The *Beagle*’s officers performed much of the surveying work on smaller boats where the chronometers were treated with as much care as on the main vessel. Fitzroy provided a description of the five chronometers placed on board the cock-boat *Paz*: ‘the rates of those useful machines were not injured even by the continual as well as sudden motions of so small a vessel. They were bedded in sawdust, wool, and sand, within a large tub, which was secured to the deck under the cabin table of the Paz, not far from the centre of least motion'.[35]

Suspension, chronometer tables, beds of wool, hair or sawdust were all designed and applied to minimise the irregular going of the chronometers caused by the motion of the vessel. In this period there was no agreement on the best way to prevent or to minimise this and the method adopted relied on the captain's discretion. Arctic explorers considered suspension a suitable method for the specific conditions they faced. The limited evidence presented here suggests that chronometer tables became more common in surveying vessels. Fitzroy deemed the chronometers' gimballed boxes sufficient and fixed them on shelves embedded in sawdust. This choice was also a direct result of Fitzroy's belief that chronometers were not affected by the motion of the vessel: 'Though so deep in the water, our little vessel's movements were uncommonly easy, and all our best timekeepers being hung in particularly good jimbals, I had no fear of their rates being altered, except by the effect of a change of temperature'.[36] During extreme movement caused by 'strong southerly gales' that 'raised a high sea … such motion did not affect them materially, and that alterations of their rates were caused chiefly, if not entirely, by changes of temperature'.[37] Temperature, according to Fitzroy, caused irregularity. We can see how officers were keen to prove they understood how external factors affected chronometers, as they could then prove that they had taken the correct steps to remedy any interference.

[35] Robert Fitzroy, *Narrative of the Surveying Voyages of His Majesty's Ships* Adventure *and* Beagle*, Proceedings of the Second Expedition 1831-36*, (London: Henry Colburn, 1839), p. 295
[36] Fitzroy, *Proceedings of the Second Expedition 1831-36*, p. 45
[37] Ibid, p. 83

Instrument epistemology

I have shown how epistemological authority was transferred from the Royal Observatory to the ship's captain at sea. Initially, in the late-eighteenth century, astronomers accompanied and trained captains to ensure the credibility of their practices. By the 1820s, this epistemological authority was transferred by the Royal Observatory, by issuing chronometers that had been tested and validated through a testing regime determined by astronomers and mathematicians. By these means, practices at sea were assured a certain amount of credibility. Increasingly, however, officers without specific astronomical training were issued with chronometers from the Royal Observatory. This meant that, over time, considerations regarding the proper instruction and management of instructions also gained in importance. That is to say, instrumental authority and the related authority bestowed on users and managers was something that was crafted over time. Credibility could not yet be straightforwardly assured, however, as this rested on the premise that the instruments behaved correctly. By 'correct' behaviour, I mean the ability of an instrument to function adequately, as determined by 'the reliable, regular predictable performance of the artifact'.[38] Even when users were supplied with the best instruments (i.e., the premium prize winners from the Greenwich Trials), equipped with knowledge of the theory underpinning their use with appropriate training to use them, and had them slung in gimbals or placed on a chronometer table, an instrument in a 'state of disrepair' could still undermine its function and the credibility of the knowledge it was supposed to create.[39] Even with the best of care, chronometers could easily slip into states of disrepair. As a result, the status of the instrument could become suspect, and its reliability called into question.

[38] Davis Baird, *Thing Knowledge: A Philosophy of Scientific Instruments*, (Berkeley, CA: University of California Press, 2004), p. 122

[39] Schaffer, 'Easily Cracked', pp. 706-717

Schaffer detailed accounts of instrumental disturbance ranging from microscopes, a Bird quadrant, a Ramsden sextant and a Troughton equatorial telescope. With these examples, Schaffer points out that 'states of disrepair became the norm, yet adequate performance was hard to define'.[40] In this sense, the chronometer faced the same problems as others have identified with the compass and the dip needle. Dunn has demonstrated the 'ambiguous status of instruments', where compasses switched 'status', from tools to investigate magnetic phenomena to being the 'subjects of investigation' themselves.[41] Goodman too has shown how magnetic instruments suffered from travel and geographical interference, as well as an inherent degradation of their magnetism. During travel, subjected to a variety of factors, the magnetic needle (of the dip sector) became 'unsteady & unsettled'.[42] It was particularly important in the study of terrestrial magnetism that the status of an instrument, or needle in this case, was known for the later reduction and comparison of the observations.[43] Withers pointed out that 'Error … was tolerated in reporting what the instrument did: that is, accuracy was always relative, measurement a moral judgement of the degree to which, and how often, devices did not function as they should'.[44]

As was emphasised by contemporary authors and commentators, chronometers were considered inherently unreliable, due to their irregular going. Chronometers accordingly required officers constantly to judge which instrument was functioning as it should and the degree of trust that could be placed in it. The reason could be clear-cut; instruments broke down due to internal mechanical failure or human error, such as their being dropped. The

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[40] Schaffer, 'Easily Cracked, p. 711

[41] Richard Dunn, 'North by Northwest? Experimental Instruments and Instruments of Experiment', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), pp. 57-75

[42] Goodman, 'Proving Instruments Credible', p. 255

[43] Ibid, p. 252

[44] Withers, 'Geography and "Thing Knowledge"', p. 685

ability to 'troubleshoot' was a fundamental aspect of chronometer use, and to demonstrate one's ability to do so helped validate claims to accuracy – in both the device and the user.

States of disrepair

Despite the best care, instruments failed. Of the eleven chronometers on board the *Hecla*'s first voyage under Parry, three stopped working completely. The first to stop was Finer and Nowland's chronometer. As noted, this was eventually attributed to internal rust. Arnold 404 was 'laid aside' after stopping from an 'unknown cause' in May 1820. Arnold 369 was found to have stopped when it was taken down to be wound in June 1820. Attempts to set it going again failed and this chronometer was then 'reserved for the examination of the maker'.[45] Inspection by the makers on return found that both chronometers had broken mainsprings, either due to flaws in the steel or as a result of the low temperatures, where mainspring breakages were more common. Another failure occurred at Winter Island in 1822, when Arnold 369 had stopped, but was set going again after Mr. Fisher 'removed a long hair from the balance'. It stopped again four weeks later and 'as it was considered advisable not to open it, and as it could not be set agoing, it remained down from that day'.[46]

Although material faults and the effects of the weather may have been out of users' control, there were also many occurrences where users were at fault. An unnamed officer dropped chronometer P&F 423 after 'which its rate was so much increased as to render it unserviceable for the remainder'.[47] On another occasion, an observer removed a pocket chronometer too quickly when noting the time of an observation, a fact which caused it to

[45] Parry, *Journal of a Voyage, 1819-1820*, Appendix, p. ix
[46] Parry, *Appendix to Captain Parry's Second Voyage*, p. 15
[47] William Edward Parry, *Journal of a Third Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific performed in the years 1824-25 in His Majesty's Ships* Hecla *and* Fury, (London: John Murray, 1826), Appendix p. 36

stop. P&F 2109 stopped when it was taken down for comparison.[48] Its rate was subsequently deemed too irregular, even for taking observations, and Parry selected a pocket chronometer from the *Fury* to replace it: P&F 49 which was also supplied by the government. To list thus all the instances where chronometers failed is not the point. It is more interesting to explore how users dealt with these issues and what they meant in terms of trust and credibility. A chronometer with a broken mainspring was in an obvious state of disrepair and, unable to tell the time, a useless object until it could be repaired. Even if repair was possible, for some users it would still remain suspect.

In the Arctic, users were restricted in terms of what they could do when an instrument failed. They could not rely on global maritime networks which allowed communication at foreign stations, ports and with other vessels, and through these avenues, the Admiralty in London. These trade routes provided options for chronometer users: they could request a new instrument from the Admiralty (via ships sailing to and from London), have it repaired or purchase a replacement overseas, and in some cases, even exchange it with a chronometer supplied to another Royal Navy ship. Owen, Foster and Fitzroy had access to and used these networks during their expeditions. This brings into focus another issue: how did this affect the trust that officers placed in individual chronometers?

Instrument makers established themselves at trade ports, providing that vital condition of all technology: repair and maintenance.[49] Both Foster and Fitzroy made use of these services. Foster wrote to Croker concerning this: 'about a fortnight ago, the main spring of one of the chronometers (Dent 2) broke; and although it has since been refitted, and replaced, yet I fear from its irregular going hitherto, it will not hereafter answer the

[48] Parry, *Journal of a Voyage 1819-1820*, p. xvi
[49] Stephen Graham and Nigel Thrift, 'Out of Order: Understanding Repair and Maintenance', *Theory, Culture & Society*, 24, (2007), pp. 1-25

conditions of a chronometer for this voyage'.[50] Earlier that year Foster had some trouble with the standard chronometer: McCabe 167. On route between St Martin's Cove (Cape Horn) and the Cape of Good Hope, McCabe 167 had stopped.[51] Foster had the chronometer repaired but also requested to be supplied with one of the government chronometers in charge of Mr Fallows at the Cape Observatory to 'add to the accuracy of longitude of the places yet to be visited'.[52] Mr Fallows agreed to loan Wedenham 929 on condition that it would be returned as soon as Foster returned to England. Foster noted fluctuations in the rate of McCabe 167 since its repair at Cape Town and that it did not perform 'so well as could be desired'.[53] Foster saw a chance of sending it to England in the *Albatross* tender to be examined. He was informed that lieutenant Arundell's Earnshaw 1024, went 'remarkably well' and wished to have it in lieu of McCabe 167, which went 'sufficiently uniform for the mere purposes of navigation'.[54] This is an issue that occurs in the orders to Fitzroy, as it was specified by 'their lordships' direction that no senior officer who may fall in with Commander Fitz-Roy, while he is employed in the above important duties, do divert him therefrom, or in any way interfere with him, or take from him, on any account, any of his instruments or chronometers'.[55] It clearly indicates that not all chronometers were equal and although many were deemed sufficient for the *mere* purpose of navigation, others were not, specifically those issued to these expeditions. Foster also returned P&F 799 with the *Albatross* as it had stopped 'yesterday from some unknown cause'.[56] Foster requested one

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[50] Henry Foster to John Wilson Croker, HMS *Chanticleer*, Ascension Island, 23 May, 1830. TNA, ADM1/1817
[51] Astronomical observations, HMS *Chanticleer*, 1828. UKHO, AO32: SFD7/7/1/9
[52] Henry Foster to John Wilson Croker, HMS *Chanticleer*, Table Bay, Cape of Good Hope, 10 December, 1829. TNA, ADM 1/1817
[53] Henry Foster to John Wilson Croker, HMS *Chanticleer*, Ascension Island, 24 February, 1830. TNA, ADM1/1817
[54] Ibid
[55] Fitzroy, *Proceedings of the Second Expedition 1831-36*, p. 24
[56] Astronomical observations, HMS *Chanticleer*, 23 April, 1830. UKHO, AO32: SFD7/7/1/9

in lieu to be sent to Maranham, as he required 'the aid of a pocket chronometer in the execution of the service required of me at Porto Bello'.[57] In Port Spain, Trinidad, Foster attempted to have Murray 555 repaired after the mainspring detached but the 'local artists' could not reattach it.[58]

As was briefly described in chapter 3, William Owen purchased three chronometers overseas to replace those that broke down. These were intended to replace those used as deck watches; Owen believed the chronometer used as the standard could only be supplied by the Admiralty.[59] This confirms the status of the Royal Observatory as an authority on chronometers. Owen experienced many problems with his instruments. He reported of Arnold 503 that it 'was good for about eleven months but for three years has been worth nothing'.[60] This chronometer, considered 'useless' by Owen, was nevertheless supplied from the *Leven* to Captain Penchas of HM sloop *Esk* in February 1825, although for what purpose is unfortunately not mentioned.[61] The Hydrographic Office received Arnold 1970 in November 1822 after its mainspring had broken during the survey.[62] Rather than go to the trouble of requesting an alternative instrument from the Admiralty, Owen instead purchased a replacement (Arnold 1891) at the Cape of Good Hope.[63] At the same time he purchased a pocket chronometer (French 1809), not as a replacement but to complement the chronometers.[64] Owen may have had good reason to purchase a replacement chronometer

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[57] Henry Foster to John Wilson Croker, HMS *Chanticleer*, Ascension Island, 24 February, 1830. TNA, ADM1/1817

[58] Henry Foster to John Wilson Croker, HMS *Chanticleer*, Port Spain, Trinidad, 7 December, 1830. TNA, ADM1/1818

[59] Stuart Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey', *Antiquarian Horology*, 40, (2019), pp. 208-209

[60] List of Instruments on Board HMS Leven, enclosure in John Barrow to John Pond, 20 November, 1826. CUL, RGO 5/229, ff. 360r–361r

[61] William Fitzwilliam Owen to John Wilson Croker, Lambeth Place, 2 December, 1826. TNA, ADM1/2271

[62] Thomas Hurd to John Pond, Hydrographic Office, Admiralty, 20 November, 1822. CUL, RGO 5/229, f. 75r

[63] John Barrow to John Pond, Admiralty Office, 7 January, 1823. CUL, RGO 5/229, f. 84r

[64] John Barrow to John Pond, Admiralty Office, 1 September, 1823. CUL, RGO 5/229, f. 121r

directly, as he spent almost a year waiting for Arnold 323 to be sent from the Royal Observatory.[65] By 1825, Owen wrote to the Admiralty that 'our timekeepers have become very faulty, requiring much loss of time and great pains to find the necessary corrections for them'.[66] But when Owen described Arnold 498 as 'an excellent watch but now appears to want cleaning', he did not consider using an overseas repair service.[67]

Trust in a repaired device varied. In Valparaiso, Mr Roskell, an agent for the chronometer makers Robert Roskell in Liverpool, undertook servicing of instruments.[68] Here officers could have their chronometers cleaned and repaired, and Captain King (on the *Beagle's* first voyage) wrote of his satisfaction of the work of the agent, describing him as 'quite competent'.[69] Owen thought otherwise: 'Captain Kings chronometers I have understood were very frequently in watch makers hands at Rio de Janeiro and at Valparaiso this fact does not increase my faith as to very precise results'.[70] On the previous voyage with Captain King, Fitzroy had purchased instruments and chronometers for the *Beagle* at Valparaiso.[71] Fitzroy used these overseas services again during the *Beagle's* second voyage. On 9 May 1833, chronometers B, O and P were 'sent on Shore to Mr Bennetts to be cleaned'.[72] It is unclear who 'Mr Bennett' was, only that he was in all likelihood located in Montevideo.

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[65] Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey', p. 209
[66] William Fitzwilliam Owen to John Wilson Croker, HMS *Leven* at sea, 16 May, 1825. TNA, ADM1/2270
[67] List of Instruments on board HMS Leven belonging to His Majesty, enclosure in John Barrow to John Pond, 20 November, 1826. CUL, RGO 5/229, f. 360r
[68] Phillip Parker King, *Narrative of the Surveying Voyages of His Majesty's Ships* Adventure *and* Beagle*, between the Years 1826 and 1836 Vol 1. Proceedings of the First Expedition 1826-1830*, (London; Henry Colburn, 1839)
[69] Phillip Parker King to John Wilson Croker, HMS *Adventure*, Valparaiso, 29 July, 1829. TNA, ADM1/2031
[70] William Fitzwilliam Owen to Francis Beaufort, HMS *Eden*, May, 1831. UKHO, MP58
[71] Admiralty digest, tab 98.4, Mathematical instruments. TNA, ADM12/272
[72] Beagle rate book, December 1831 – November, 1836. UKHO, OD821

Figure 5.6: Left: Eight-day box chronometer by George Margetts, no. 163 (NMM ZBA0672); Right: One day box chronometer by Barraud and Lund, no. 10 (NMM ZBA0676). These box chronometers were both used during the East African Survey as hack watches, as their performance was considered poor. Betts, *Marine Chronometers at Greenwich*, p. 243-248. © National Maritime Museum.

What is more relevant to this study is *how* the instruments were assessed on their return. Little evidence remains relating to this and we must therefore rely on Fitzroy's 'principal results of the Beagle's chronometrical measurements'.[73] In these results Fitzroy listed the meridian distance measured by the chronometers in use during that particular run and subsequently selected the ten chronometers he considered to most accurately reflect the difference in longitude. Chronometers B, O and P disappeared from the list in the meridian distance between Montevideo and Port Desire (figure 5.7).

Monte Video to Port Desire.

Seventeen Chronometers. Nineteen Days.

	H. M.	S.	H. M.	S.		H. M.	S.	H. M.	S.
A	0 38	46,88	……	46,88	M	0 38	40,01		
C	……	44,08			N	……	42,75		
D	……	50,17	……	50,17	R	……	45,65	……	45,65
E	……	50,30	……	50,30	S	……	51,49	……	51,49
F	……	46,01	……	46,01	W	……	45,45	……	45,45
G	……	48,37	……	48,37	X	……	39,95		
H	……	43,01			Y	……	27,14		
K	……	56,56			Z	……	47,32	……	47,32
L	……	48,04	……	48,04	Mean …		45,48	……	47,97

Preferred………… 0h. 38m. 48,0s.

Places of observation :

Monte Video, as before.
Port Desire, at the Spanish Ruins.

Figure 5.7: Meridian distance between Montevideo and Port Desire, HMS *Beagle*. Fitzroy, *Appendix*, p. 334

Chronometer B reappeared on the next distance between Port Desire (South East coast of Argentina) and Port Famine (Chile, in the Strait of Magellan), where it was included in the selection of ten chronometers by which the distance was measured (figure 5.8).

[73] Fitzroy, *Appendix to Volume II*, p. 331

Port Desire to Port Famine

Sixteen Chronometers. Sixteen Days.

	H.	M.	S.		H. M.	S.		H.	M.	S.		H. M.	S.
A	0	20	10,57	......		10,57	L	0	20	10,35	......		10,35
B	0	20	09,39	......		09,39	M	0	20	15,84			
C	0	20	10,65	......		10,65	R	0	20	12,20	......		12,20
D	0	20	09,03	......		09,03	S	0	19	51,65			
F	0	20	10,70	......		10,70	T	0	20	39,07			
G	0	20	05,07				W	0	20	14,22	......		14,22
H	0	20	09,71	......		09,71	X	0	20	07,31			
K	0	20	02,10				Z	0	20	10,29	......		10,29
							Mean	0	20	10,51	......		10,71

Preferred........... 0h. 20m. 10,7s.

Places of observation :

Port Desire, as before.

Port Famine, old Observatory at the west side of the port.

Figure 5.8: Meridian distance between Port Desire and Port Famine, HMS *Beagle*. Fitzroy, *Appendix*, p. 335

Chronometer P reappeared in the next run, between Port Famine and San Carlos (West Coast of Chile) and chronometer O even later between Valparaiso to Callao (figure 5.9). Two other chronometers (H and K) were serviced in Valparaiso by a Mr Croft. Both were subsequently used in Fitzroy's meridian distances. It is important to point out that a chronometer that was on board ship and which was running, would always be included in the first column listing the meridian distance by all the chronometers. It is the second column that is important here: these were the instruments Fitzroy selected. If a chronometer is missing from both columns in the summary, it was either broken, employed in one of the surveying sloops (the *Adventure,* the *Paz* or the *Liebre*), or it was ashore for repair.[74]

[74] Simon C. Davidson and Peter Linstead-Smith, 'W. E. Frodsham No.1. Another Chronometer Identified from *HMS Beagle's* Second Voyage', *Antiquarian Horology*, 37, (2016), pp. 366-376

VALPARAISO to CALLAO.

Fourteen Chronometers. Twenty-five Days.

	H. M.	S.	H. M.	S.		H. M.	S.	H. M.	S.
A	0 22	07,74	......	07,74	O	0 22	08,66	......	08,66
B	......	00,51			P	......	08,97	......	08,97
C	......	07,31	......	07,31	R	......	11,33	......	11,33
D	......	06,86	......	06,86	S	......	11,39	......	11,39
E	......	04,42			W	......	12,28	......	12,28
F	......	16,60			X	......	03,30		
G	......	05,90	......	05,90	Z	......	09,36	......	09,36
					Mean ...		08,19	......	08,98

Preferred........... 0h. 22m. 09,0s.

Places of observation :

Valparaiso, as before. Callao, the Arsenal.

Figure 5.9: Meridian distance between Valparaiso and Callao, HMS *Beagle*. Fitzroy, *Appendix*, p. 336

We can see from these examples that Fitzroy, like King, had enough faith in the abilities of the instrument makers overseas to repair the chronometers to use them for his meridian distances. They judged the chronometers involved by the data they produced, not where they had been repaired. Foster and Fitzroy both used the data they had collected and recorded to analyse and select the best instruments for each meridian distance. The repaired devices were included or excluded solely on that basis. There are a few reasons why Owen may have questioned the results of Captain King's chronometers: he may have indeed doubted the abilities of the overseas instrument makers; he may have thought them to have been repaired too frequently (and concluded they were thus inherently faulty), or he may have disapproved because the longitudes measured by King did not match his own.

Questions of trust in repaired devices did not end at sea. When Owen delivered four hack watches to the Admiralty on his return to England, Pond advised that new escapements should be fitted in the instruments after examination by the makers. Barrow asked Pond to clarify 'whether by being "equal to new ones" new hack watches is meant, or chronometers fit for any service, if the latter, their lordships desire that the proposed repairs may be done'.[75] Pond considered them after repair to be 'fit for any service' indicating his trust in the abilities of the London instrument makers. The same caution can be found at Parramatta Observatory, where the local government clockmaker was trusted to clean a Breguet timekeeper, but was not allowed near the sidereal clock.[76]

Trouble-shooting

Not all cases of malfunction were as obvious as the examples given above, and in most cases, it was not necessarily obvious that an instrument might not be working adequately. This section examines the problems Parry faced in the Arctic due to the extreme temperatures they experienced. Parry's experiences have been selected as an example as he not only detailed the problems they faced, but also the solutions that they applied.

As Fitzroy stated, temperature variations caused significant problems. But even stable temperatures could cause difficulties, as users in the Arctic were well aware. Extremely low temperatures caused numerous issues on Parry's first voyage. Many of the instruments initially began losing rate in the intense cold and stopped if they were not transported back to the warm cabin in time. This effect was attributed generally to the congealing of the oil at low temperatures. But in one particular case, the problem was the inadequate temperature compensation of the instrument itself. Parry testified that the chronometers supplied by Parkinson and Frodsham (which had their temperature compensation specifically calibrated for the Arctic region), fared better than the other instruments. Although they were affected by the cold, none stopped or altered their rates as much as the others did. Each chronometer seemed to have a limit at which it would slow down considerably before stopping. Parry

[75] John Barrow to John Pond, Admiralty Office, 19 September, 1826. CUL, RGO 5/229, f. 353r
[76] Simon Schaffer, 'Keeping the Books at Paramatta Observatory', in: *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture*, David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), p. 131

found that box chronometers would stop between and 15° Fahrenheit (-10°C) and 6° Fahrenheit (-15°C). Observers using pocket chronometers outdoors had severer conditions to compete with, with temperatures ranging between -20° Fahrenheit (-29°C) and -40° Fahrenheit (-40°C) during the three- or four-hour periods of lunar observations. Despite these extreme conditions, Parry testified that the chronometers continued to work with little effect on their rates, if the duration of exposure was not too long or the temperature too low. But what was too long or too low could only be determined by exposure. Having found that many pocket chronometers stopped whilst being used at temperatures around and below -35°C, observers adopted the use of tin cans filled with heated sand. Placing the chronometers on these tins during observations prevented them from stopping.

During each voyage that Parry commanded in search of a North-West Passage, the crew spent many months overwintering with the ships beset by ice. This situation only added to the challenges of maintaining the instruments. On the first voyage, Parry had kept the chronometers 'suspended within five feet of the cabin fire'.[77] This was a direct result of Sabine's previous experience whilst he served on the 1818 expedition under Captain John Ross. Sabine had observed that the rates of the chronometers altered when Ross discontinued the fire in his cabin.[78] A limited fuel supply unfortunately led to severe changes in temperature, despite leaving the chronometers in proximity to the cabin fire. Parry learned from this experience, and during the winter of the second voyage, he placed the chronometers on bookcases on either side of the cabin fire, indicating a process of trial and error in using these instruments in Arctic conditions.

[77] Parry, *Journal of a Voyage, 1819-1820*, Appendix, p. vii
[78] Edward Sabine, Journal and letters during Ross's expedition, 1818. PWDRO, 581/81

Regulating officers

The management of chronometers did not end with their receipt and installation on board ship. The consensus was that the less chronometers were interacted with the better they functioned, but they still required regular winding and comparison. Whilst winding a chronometer may not require much skill, officers still required some guidance on how this should be done, as it could and did go wrong. This was another point of instruction in Richard Owen's *Essay*, where he detailed not only how, but also when chronometers should be wound. This was an important point as it appears in almost all of the early instructions to astronomers and chronometer users of the late eighteenth century, and was one that writers of the nineteenth century continued to reiterate. It also became increasingly common for ships to carry more than one chronometer, leading to a greater focus on comparing one with another. This was another area of chronometry which emerged in other areas of instrumental practice and was incorporated into chronometry at sea as it developed.

Comparing chronometers was not as straightforward as it may sound. Richard Owen described several methods of comparison, including details of how and when to record it. For all of these case studies, comparison was vital to help officers determine which chronometers could be relied upon. Inherent to this practice became the selection of a standard chronometer. Here, judgement mattered, as users adhered to hierarchies of instruments, where some were trusted to provide adequate data and others not. When comparing the chronometers, it mattered which instruments were selected as 'reliable' and which as 'unreliable'.

Although it would seem that daily winding would fit into the regulated rhythm of shipboard life, forgetting to wind them was nonetheless a regular occurrence. It was certainly common enough to warrant commentary. Parry noted that 'those who have been accustomed to the charge of chronometers for any length of time, and who know the weight and importance of that charge, it will be considered as deserving no small credit on the part of these gentlemen, that, for a period of nearly twenty months, during which, eleven chronometers were on board the Hecla, only two instances occurred of a single chronometer being suffered to go down by neglect'.[79] The duty of winding chronometers required a certain amount of authority. Parry mainly assigned this duty to his astronomer and one of his officers. On this first voyage, these were Sabine and William Harvey Hooper, Parry's purser on the *Hecla,* of whom he later wrote to his brother 'Hooper is with me, and, as usual, <u>my right hand</u>'.[80] Hooper assisted both Fisher and Foster on the second and third voyages, winding and comparing the chronometers daily at noon. Parry's accounts of all three voyages recorded multiple occasions of the chronometers not being wound. Numerous instances where a single chronometer had not been wound were dutifully recorded in the appendix, evidence that keeping track of which one had been wound and rated could cause confusion. It was generally assumed that letting a chronometer run down would result in a change of rate, and was thus best avoided. Jennings' up-and-down indicator was intended to prevent this from happening, although in practice it caused the chronometer to stop. Despite this, although up-and-down indicators were rare on early nineteenth-century chronometers, they became prevalent in most instruments by the 1840s.[81] This indicates that the duty of winding chronometers continued to be somewhat problematic, at least enough to warrant this technological addition to the instrument.

Richard Owen specifically pointed out that winding and comparison should occur at the same time. This was intended to minimize interaction with and therefore movement of the instruments. This was another point where William Owen found fault with Foster's

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79 Parry, *Journal of a Voyage, 1819-1820*, p. xii

80 William Parry to his brother Charles Parry, 16 January, 1824. SPRI, GB 15: MS 438/26/164

81 Jonathan Betts, *Marine Chronometers at Greenwich*, (Oxford: Oxford University Press, 2017), p. 103-107

method. By suspending the chronometers tightly within separate cots, 'the process of winding and comparing daily subjects them to much irregular movement'; movement that both Richard and William Owen were keen to avoid.[82] Winding and comparing should thus occur daily at noon. Regularity was key. Eight-day watches were wound only on Sunday, as that would 'always be remembered better than any other day in the week'.[83] The winding and comparison of the chronometers had to be reported before being allowed to 'pipe to dinner'.[84] If discipline and good habits did not work, withholding dinner certainly should ensure the duty was not forgotten. For merchant vessels, Richard Owen warned against relying on only one man's memory: chronometry should not be a solitary practice. Regularity in winding was one thing, careful handling was another. The actual physical manner of winding a pocket chronometer was described, as the practice of turning the watch on the key was 'very common, and very bad'.[85] Instead, the hand holding the chronometer should rest against the body to prevent rotation, and the turns of the key should be counted so that the last turns could be 'made gently and carefully, until it is felt to butt'.[86]

Practices were different on the *Beagle.* Fitzroy ordered that the 'chronometers are to be wound daily between ½ past 8 and 9 in the forenoon & they are to be compared at noon. The eight-day watches are to be wound every Sunday morning. The daily winding & the comparison of the chronometers is to be reported to me or in my absence to the commanding officer by one of the following officers. 2nd lieutenant, assistant surveyor, master. Masters assistant'.[87] Stebbing ('under the inspection of Mr. Stokes and myself') was in charge of winding and comparing the chronometers in addition to his duties of repairing

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[82] William Fitzwilliam Owen to Francis Beaufort, May, 1831. HMS *Eden*, UKHO, MP58
[83] Owen, 'An Essay on the Management and Use of Chronometers', p. 7
[84] Ibid, p. 6
[85] Ibid, p. 7
[86] Ibid, p. 7
[87] Captain's orders relating to the voyage of the Beagle, 1831-36, copied by Stokes from the original, signed by Fitzroy. NMM, STK/15

instruments, assisting in observations, writing for Fitzroy and taking care of the book collection.[88] With a total of twenty-two chronometers, we might imagine that this may have taken up at least half an hour, and in rough conditions possibly considerably more, although nobody commented on this. Initially, it may have been prudent to separate the winding from the comparison, as it would be easy to forget if one had been wound or not. Yet practices were not set in stone and users altered them if necessary. Initially, winding and comparison took place at the same time each morning, as advised by Richard Owen. But within the *Beagle's* comparison book, we can see that the practice was changed. Inserted between the comparisons on 9 and 10 February 1831 was an additional noon comparison. On the final page of that month Stebbing wrote the following remark in pencil: 'altered the time of comparison to noon'.[89] It can be reasonably assumed that Stebbing initially compared the chronometers during the morning winding, but after two months a decision was made to change this to noon. Potentially, winding and comparing twenty-two chronometers at the same time was too much for Stebbing. Another reason for this adaption could be related to the method of rating the chronometers. Apparent noon was determined by Equal Altitudes which would make noon comparison with the other chronometers more convenient. Practice was thus not always as straightforward as the regulations imply. On winding, Foster's comments were limited to the fact that 'they were wound up every day at noon, and compared by lieutenant Kendall and myself, with one considered as the standard'. The standard was 'no. 167, of McCabe's construction, selected for that purpose in consequence of its having obtained the highest prize from the excellence of its performance during a year's trial at the Royal Observatory at Greenwich'.[90]

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[88] Fitzroy, *Appendix to Volume II*, p. 327

[89] Chronometer Rate Book of HMS *Beagle*, 1834-36. UKHO, OD/821

[90] Astronomical Observations, HMS *Chanticleer*, 1828-31. UKHO, AO32: SFD7/7/1/7

Winding became intrinsically linked to comparison, and comparison to selecting a standard chronometer. Both these aspects required certain amounts of skill and reflection.

Comparison is a skill

Comparing chronometers was a significant part of chronometry practice at sea on ships carrying multiple instruments. We can again turn to the 1818 expeditions to understand how the practices emerged that were adopted and adapted on the Arctic expeditions under Parry's command. Ross sailed with instructions provided by the Admiralty and the Royal Society, although neither included any instructions on the use of chronometers. Kater wrote the instructions issued by the Royal Society for the scientific research.[91] These instructions related to the scientific experiments that the officers were to perform, for which Sabine accompanied the voyage. Prior to departure, the chronometers supplied to Ross's expedition were sent to Henry Browne's basement for rating. Despite the effort that had been put into rating the chronometers and the care and preservation of the instruments on board ship, no formal instruction over how to account for their performance had been issued. Sabine described this in a letter to Browne written on board the *Isabella*:

> what value would an hour or two's conversation with you be of use now. However it will come altho' not in time to benefit me for this voyage. I have followed your direction in working everything at full length in a book, & find the advantage of it; everything is referred to there in consequence. How much more will it be necessary [since?] our chronometers commence irregularities. How any true longitude from day to day is to be deduced from … books kept in the Isabella except my own chronometer book I cannot see. There is no mention kept of what each chronometer shews at mean noon. Therefore altho' our observations may give our daily longitude sufficiently near for purposes of navigation, it will be … an impossibility hereafter to deduce the true longitude from them, when we may be able to form a judgement of their deviation from the rates allowed.[92]

[91] Henry Kater, *Instructions for the Adjustments and Use of the Instruments Intended for the Northern Expeditions*, (London: Printed by W. Bulmer, 1818)
[92] Edward Sabine, Journal and letters during Ross's expedition, 1818. PWDRO, 581/81

From this passage, it is clear that by 1818 there were no guidelines on how to keep an account of the chronometers beyond what was necessary navigation. Sabine was not the only one who commented on this lack of regulation. In a letter to Barrow in 1820, Hall also advised keeping 'an account of the performance of every chronometer' which would 'enable the officer in charge of the establishment to form a better estimate of the merits of each watch than he could do by merely examining it on shore'.[93]

Sabine would have been instrumental in the practices that emerged on these voyages. He followed procedures that were similar to observatory practices and his pendulum experiments, as the chronometers supplied were not only used for navigation but also to aid in the pendulum experiments. Kater described the process of comparing the chronometers to the astronomical clock in his *Instructions for the Adjustments and Use of the Instruments Intended for the Northern Expeditions.* To compare the chronometers with the clock, one should 'place the ear close to the clock, and begin counting the seconds, looking at the same time at the chronometer No. 1, and on counting 60 seconds, which will complete the minute of the clock registered, mark carefully the second, and fraction of a second shewn by the chronometer, and set this down together with the minute and hour'.[94] A total of twelve chronometers was supplied to the Northern expeditions of 1818 under command of Captain John Ross (HMS *Isabella*) and Captain David Buchan (HMS *Dorothea*), but it remains unclear which instruments were issued to which ship or officer. Captain's Ross and Buchan received two Arnold pocket chronometers each, but the eight remaining box chronometers were first sent to Henry Browne's house at 2 Harley Street, according to Hurd's report.[95] They were sent there to have their rates compared against a clock 'whose rate was known' and as a

[93] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956
[94] Kater, *Instructions for the Adjustments and Use of the Instruments Intended for the Northern Expeditions*, p. 6
[95] Thomas Hurd, 'List of chronometers issued between the 1st August 1817 and 1st August 1818'. UKHO, MLP82

result, Sabine determined 'their rates, therefore, as deduced from so long a period of trial might be expected to be steady'.[96] We can see how these practices emerged through the experience users had with other instruments within their scientific and navigational practices; from the pendulum experiments to the compass.

Once comparison was completed, users would then produce a table of comparison. With these daily comparisons, users could judge the going of the chronometers in the absence of astronomical means. Irregularities were detected by tabulating the differences at noon each day between the standard and the other chronometers. Richard Owen found the comparisons useful as it allowed 'us to detect the vacillations of any of the Chronometers, and to get their corresponding results at any required time'.[97] Through comparison, operators could decide which chronometers were to be used for computing longitude. This would, however, make for a considerable amount of work, depending on the number of chronometers being carried on the voyage. When multiple chronometers were used, only the standard would be rated, and the rates for all the others were subsequently obtained through comparison. For Parry, Sabine, Fisher and Foster, comparing multiple chronometers may not have given rise to any difficulties since they were all well trained in their use. Fitzroy, having completed his education at the Royal Naval College under James Inman, who oversaw the care and rating of chronometers there, must also have been accustomed to the practice and, if not there, then certainly aboard the *Adventure* with Captain King. Stebbing, the instrument maker employed by Fitzroy, may have been familiar with the practice of rating chronometers through his father's business in Portsmouth, although there is no evidence that they repaired or rated chronometers within their business as 'working Optician and

[96] 'Abstract of Observations for determining the *Isabella's* latitude and longitude by Edward Sabine'. TNA, BJ3 62/1

[97] Owen, 'An Essay on the Management and Use of Chronometers', p. 8

Manufacturer of Optical and Mathematical Instruments'.[98] For others less well trained, however, comparing eight, fifteen or twenty-two chronometers a day may not have been easy work.

The question of skill more readily springs to mind when you consider an officer attempting to take lunar observations with a sextant on a windy day at sea, on the deck of a rolling ship, particularly in Arctic conditions where the atmosphere often distorted the appearance of the surroundings and the cold instruments caused burning sensations on the hands if used for too long. But it also applied to chronometry, although again this aspect was not discussed in manuals of instruction. Richard Owen's essay described various methods of comparison, depending on whether the instruments were in the same location, one above and one below decks, or on different ships altogether. For most users, the chronometers were kept in one place below decks and could be compared by 'one person, in following the beats of the standard by his ear, and counting them to an even ten seconds, whilst his eye marks the corresponding time on the other watch; two of these comparisons should be made with each, to detect and prevent mistakes'.[99]

In 1861, Charles Shadwell described how the process 'requires much practice and self-confidence, and demands also a more delicate organisation of ear and eye than is possessed by all persons'.[100] Shadwell continued that 'for the facility of comparison with the other chronometers it will be found convenient to arrange the chronometers in their box in such a manner that the standard shall occupy a central position among them. The XII and VI hour marks should all be parallel to one another, and to the "fore and aft" line of the ship'.[101] He

[98] Julian Holland, 'George James Stebbing: Captain Fitzroy's Instrument Maker: Part One', *Bulletin of the Scientific Instrument Society No. 116*, (2013), pp. 22-29, quote on p. 22
[99] Owen, 'An Essay on the Management and Use of Chronometers', pp. 7-8
[100] Charles F. A. Shadwell, *Notes on the Management of Chronometers and the Measurement of Meridian Distances*, (London: J. D. Potter, 1861), p. 28
[101] Shadwell, *Notes on the Management of Chronometers*, p. 26

also recommended the use of letters as identifiers rather than the maker's name and number since 'the highest authorities' followed this practice (Shadwell unfortunately did not specify who the highest authorities were).[102] Although written two decades after the *Beagle* departed on her second voyage, Shadwell's instructions (which continued over three pages) described how Stebbing was likely to have performed his comparison in the 1830s.[103]

> The observer, with a book in hand, containing a ruled form for the entry of the time shown by the several chronometers takes a beat from the standard five seconds before the arrival of the second hand at any five or ten seconds mark, and then quickly casting his eye on the chronometer to be compared, counts with his ear the ten beats which elapse before the second-hand arrives at the mark selected; at the completion of the interval he reads the other chronometer, and the comparison is effected. The operation being repeated a second time to correct the first judgement, the final observation is recorded. It will be found convenient to make the first comparison at 50s, or at 20s, and again at the minute or half minute for the final result.

This eye-and-ear method was a well-established precision routine in the observatory, and those who mastered the process had done so after a long apprenticeship.[104]

Setting standards

Chronometers were not regarded equally by their users. Rather, users such as Parry designated hierarchies of reliability. During the 1818 expedition of the *Isabella* and the *Alexander,* Ross, Sabine and Parry used compasses to investigate magnetic phenomena in the Arctic. But the effects of the phenomena they were investigating also rendered the device unreliable. On each ship, one compass was selected as 'a standard', to which the other instruments were compared. It was placed in a position which would reduce external

102 Shadwell, *Notes on the Management of Chronometers*, p. 26
103 Ibid, p. 27
104 David Aubin, Charlotte Bigg and H. Otto Sibum, 'Introduction: Observatory Techniques in Nineteenth-Century Science and Society', in: *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture*, David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham and London: Duke University Press, 2010), p. 10

interference, and thereby increase the credibility of the observations.[105] A similar process was seen with the chronometer, where a reference chronometer was selected to simplify the procedure of calculating longitude. It also served as a mediator between the chronometers that were kept securely in a cabin and the pocket chronometer or hack watch used on deck or on shore to time the observations. Parry's demarcations were clear. He employed a standard chronometer, or as it was described on the first voyage, 'the watch by which the time of all observations should be noted, its rate being small and very uniform'.[106] Then followed those chronometers that were used 'in the determination of longitudes', those that 'had best preserved a mean rate'.[107] Finally, the rates of the chronometers not included in the longitude determinations were listed in a table. Excluded from either group were the pocket chronometers used for taking observations on shore.

The reason and justification for choosing a specific instrument as the standard varied depending on particular circumstances. Sabine selected P&F 228 for Parry's first voyage, on the basis of its good performance on the previous expedition under Captain Ross on HMS *Isabella* in 1818. On this voyage, Parry and Sabine worked on the basis of intervals. An interval was the period between two ratings of the chronometers. For example, on departure, Sabine used the rates as determined in Browne's basement. Later, the party took a total of 1,209 lunar distances in June and August, on route to Davis Strait. Sabine thereby retrospectively calculated what the Greenwich Mean Time (GMT) was at the instance of Local Mean noon 22 July, 1819 (the middle day of the observations). By then comparing the time of GMT as determined by the chronometers to that determined by the lunars, Sabine was able to rate the chronometer again. As Sabine determined the first rates at midnight on May 6 of that year, this meant that the interval to which the newly calculated rates were (retrospectively)

105 Dunn, 'North by Northwest', p. 68
106 Parry, *Journal of a Voyage 1819-1820*, Appendix, p. vi
107 Ibid, p. vi

applied was a period of seventy-six and a half days. During the course of the voyage the rates were again determined at Winter Harbour (by lunar observations) and finally on return to England. Following the observations and subsequent rating of the instruments during the stay at Winter Harbour, P&F 259 was appointed the standard chronometer as it was believed 'to have preserved the most steady and uniform rate throughout the season'.[108] Fisher again selected P&F 259 on Parry's second voyage, based on its previous good performance under Sabine.

From 1822, the Premium Trials at Greenwich also served as a criterion for selection. During the third voyage under Parry's command, Foster used Murray 816 as the standard, as it had gained the premium reward during the twelfth months trial at the Royal Observatory. Again, in 1828, having been equipped with the best chronometers following the Greenwich Trials, Foster used McCabe 167 as the standard on HMS *Chanticleer*, due to it having performed best that year. Owen did not specify in his essay which chronometer was selected as a standard as it was written as an instructive guide, not an account of the actual practice observed. It is evident from the examples given, however, that Arnold 498 was used as the standard for the majority of the voyage but was replaced with Arnold 323 after being supplied from Greenwich via the *Owen Glendower* in 1825. In his essay, Richard Owen recommended that users should select a chronometer 'that beats distinctly, and to half seconds, as it will be found to give great facility in comparing, and in most cases render the assistance of a second person unnecessary'.[109] He made no mention of selecting a chronometer with the smallest or steadiest rate: practical advantage was accorded greater significance. Fitzroy mentioned no justification for selecting his standard, only that 'the two supposed to be the best' were used.[110] These were Molyneux 1415 (an eight-day

[108] Parry, *Journal of a Voyage 1819-1820*, Appendix, p. vii
[109] Owen, 'An Essay on the Management and Use of Chronometers', p. 7
[110] Fitzroy, *Appendix to Volume II*, p. 329

chronometer owned by Fitzroy) and French 4214 (an eight-day chronometer supplied by the Admiralty, see figure 5.10). French 4214 had previously performed well on the *Chanticleer,* and this would certainly have been taken into account. The chronometers had been 'embarked, and permanently fixed' on board for rating a month before the ship departed and the results of this would also have formed the basis for their selection.[111]

Figure 5.10: 8-day box chronometer by James Moore French 4214. This box is all that remains of chronometer French 4214 after it was lost in HMS *Erebus* during John Franklin's fatal expedition in search of a North-West Passage. The box was found during an expedition led by an American explorer, Charles Francis Hall, 1864-1869. (NMM AAA2233). Betts, *Marine Chronometers at Greenwich*, pp. 317-318. © National Maritime Museum.

[111] Fitzroy, *Appendix to Volume II*, p. 325

Comparison tables were a crucial health check for the chronometers. Officers used them to categorise their instruments into hierarchies of trust, with the standard chronometer at the top. As mentioned earlier, this was generally the chronometer that after a period of rating had the smallest and steadiest rate. Chronometer P&F 228, had performed so well on Parry's first expedition that it was selected as the standard for the second voyage. But after a considerable period of rating during the winter of 1821-22, the officers found that P&F 259 kept a better rate and this instrument was selected instead as the standard. An earlier interval of rating the chronometers also led to changes in the chronometers used for the determination of longitude.

Within Owen's practices the distinctions between chronometers were also clearly defined. Owen requested hack or deck watches, which were chronometers he considered good enough for measuring small intervals of time but not for the determination of longitude. Owen believed that moving chronometers was detrimental to their going and preferred to limit this where possible. By thus acquiring deck watches, Owen hoped to prove his measurements were reliable, due to not moving the superior instruments that he used for his longitude determinations; those instruments he kept secured below the deck. Chronometers were not the only timekeepers Owen employed during the survey; he mentioned a 'small watch by Mr. Massey, of Prescot, in Lancashire, which beat *twelve* times in a second, this we found useful for measuring distance by sound, and to no other purpose did we ever apply it'.[112] Owen considered a common watch accurate enough for short measurements of time.

The two voyages tasked with measuring meridian distances by chronometers (the *Chanticleer* in 1828 and the *Beagle* in 1831) adopted similar practices despite applying different criteria. Meridian distances had two important aspects: they required large

[112] Owen, 'An Essay on the Management and Use of Chronometers', p. 10

numbers of chronometers to generate data and they were required to sail between the two points of measurement as quickly as possible. This latter was intended to minimise the detrimental effects that officers experienced when chronometers were used over longer periods. Both used pocket chronometers to take observations on deck or on shore. These were then compared to the chronometer selected as the standard. All other chronometers were subsequently compared to the standard, and, based on this comparison, each captain selected which instruments should be included within the mean results for the longitude determination. The criteria for these decisions are explored in more detail in the chapters following. Foster used two pocket chronometers (P&F 699 and P&F 799) for taking observations on shore and a box chronometer by McCabe (167) as the standard against which the times of the observations were noted.

What becomes increasingly clear from these examples is that the period of time being measured played a critical role in how instruments were used. Hack watches and pocket chronometers, and sometimes even ordinary watches, were considered accurate enough to assist in lunar observations, for the determination of local time and, in Owen's case, to measure distance by sound. Measurements of relative longitudes required longer time intervals, which in turn required more consideration from officers and their instruments. For these measurements, officers reserved those chronometers they considered their best. This was because it was harder to calibrate the chronometers over time. This could only be done via extensive astronomical observation or by comparing the chronometers to known longitudes. As both these requirements took time and were not always available, chronometers could not always be rated and thus calibrated regularly or when required. The longer the period of time between ratings, the less reliable the officers considered the measurements. Thus, the period between rating chronometers gained importance and was taken into consideration when officers evaluated the results obtained by chronometers.

Conclusion

> Without considering the great improvements which have taken place in this instrument, and its supposed perfection, Captain Owen felt that, to place implicit confidence in it, might probably be fatal to the correctness and utility of our work : and the result proved the justice of this supposition, for, not one of our nine chronometers kept its rate without fluctuations, produced either by change of weather, climate, or position. In some this variation was very trifling, but in all sufficient to produce much error, unless corrected by a great deal of care and attention.[113]

From this quote we learn two things. Firstly, Owen confirmed what navigational authors had written in the late eighteenth century: chronometers were inherently unreliable due to variations in their rate. Secondly, Owen reveals why it was so important to officers to demonstrate adequate management of the instruments. No two measurements of longitude were the same, even those determined by the same instruments and methods. It was vitally important to prove the credibility of one's results, especially if they differed from those of others. Owen countered the unreliability of his chronometers with the reliability of his method. When results obtained by other voyages differed from his, he put this down to bad management on their part (disagreeing with Foster's suspended chronometers), or as in King's case, to the repair of his chronometers abroad.

As chronometers were deemed inherently unreliable, officers sought to use the proper management of them to demonstrate expertise and therefore trust in the methods applied. Consequently, the printed guidelines on chronometry practice were just as much a bid to secure credibility as they were an instruction of best practice. Equally important, they were based on users' own experiences of chronometry practice, which were shaped by a multitude of factors. As is evident from the experience of Arctic explorers, *where* the chronometers

113 William F. W. Owen, *Narrative of Voyages to Explore the Shores of Africa, Arabia, and Madagascar; Performed in H.M. Ships* Leven *and* Barracouta*, Vol. I*, (New York: J & J Harper, 1833), p. 16

were used mattered, and the specific arrangements that were made evolved through trial and error. Instrument makers adjusted the temperature compensation to cold conditions; the chronometers were suspended in slings to prevent shocks from the ice, and officers learnt to use cabin fires and heated tin cans to prevent them from stopping.

The purpose of the voyage also mattered. Owen's survey was shared between the two ships, the *Leven* and the *Barracouta,* and the additional sloops Owen purchased during his five years on the East Coast of Africa. This work required continued movement between the shore and the ships, a fact Owen considered detrimental to the going of the chronometers. Combined, the requirement of movement and the detrimental effect of movement led Owen to use a high number of deck and pocket chronometers. In this way, Owen mitigated the specific problems he faced.

Previous experience also guided practice, as we saw with Foster's approach on the *Chanticleer.* Despite the majority of the voyage not taking place in the Arctic regions, he still proceeded with the suspension of chronometers in slings. Although the approach of the chronometric measurements was based on the meridian distances made earlier by John Lewis Tiarks, the management was based on Foster's experience after serving on two polar expeditions under Parry. In addition, those officers who had gained experience in astronomical practices or through pendulum experiments were able to apply these skills to chronometry at sea. They had learned the skill of comparison, astronomical observation, and record-keeping. A growing number of officers not only had access to the best instruments, but also developed habits which led to a certain method of procedure. If these methods were to extend to all officers operating with chronometers at sea, then these practices needed to be communicated and taught to officers and seamen. Richard Owen's 'Essay' sought to address this issue by attempting to explain the process of and need for comparison to those seamen who were predominantly trained at sea, without the benefit of an astronomer. As Richard Owen wrote, his essay was not 'intended to inform the Astronomer'.[114]

As chronometers were easily disturbed, their management and regulation became increasingly common to prevent inaccuracy. The experiences and accounts of these expeditions contributed to the instructions that were gradually appearing in print. But these instructions still remained a point of debate. Owen ceased firing cannons from the deck of the *Leven* in order to prevent the vibrations from affecting the timekeepers. Later, in 1835, four surveying voyages sent out were forbidden from firing guns on account of the chronometers.[115] Not all agreed with this intervention, as Belcher complained whilst on the *Blossom* (1825-1828) that the guns of a Russian Service ship were not fired in salute 'on the plea of disturbing the chronometers, especially when one may add several guns were fired in their presence to measure base by sound'.[116] As we have seen, Fitzroy likewise did not believe that firing the guns on the *Beagle* had any effect on them, which he proved by 'by scattering powder upon their glasses and watching it with a magnifying glass'.[117]

The suspicion that magnetism affected chronometers led the Hydrographic Office to issue specific instructions to surveying officers in 1835. They were to align their chronometers with the length of the vessel with the XII-hour mark on the dial facing the head of the ship. The chronometers were to remain in this position for a month, after which their position was to be rotated by 90^{o} each month. Officers were to record the results in the chronometer journal so that the effect of this could be investigated. In 1836, Fisher was

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114 Owen, 'An Essay on the Management and Use of Chronometers', p. 3
115 Admiralty Minutes, 14 December, 1835. TNA, ADM3/232
116 Edward Belcher, Belcher's Journal on Board HMS *Blossom*, 26 May, 1826 to 12 December, 1827. SPRI, GB 15: MS1044/1
117 Fitzroy, *Appendix to Volume II*, p. 326

granted the use of 'as many chronometers as can conveniently be spared' to perform experiments on the subject. Six chronometers were issued.[118]

Owen's and Tiarks' opposition to the practice of suspension should not be seen as the end of the debate. Between 1837 and 1838, George Fisher conducted experiments to test the effect of suspension on the rates of chronometers. Fisher compared the rates of chronometers 'suspended in cots' with chronometers 'not suspended' and concluded that suspension caused an increase in their rates. He extended his experiments to determine the effect on the rates by clamping or unclamping the gimbals and placing them on 'cushions of hair', 'firm on the table' and on 'pads of wool'.[119] Fisher sent an abstract of the results to George Airy entitled 'Some experiments shewing the effect upon the rates of chronometers when placed in cots, as is usual on ship-board'.[120] The 1820s and 1830s were a period of trialling, testing, experimenting and evaluating how, in very particular circumstances, chronometers could be made to behave according to the expectations of those employing them. These examples show that although investigations were becoming common place at sea, and individual advice was forthcoming, consensus had not yet been reached.

These expeditions are also indicative of how, through careful management and scrutiny, these expeditions helped expand the uses to which chronometers could be put. On shore, through trials at the Royal Observatory, instrument makers were attempting to improve the mechanism. At sea, users were experimenting with methods and procedures that would help prevent variations of rate that were so hard to detect. Many of the instruments that were not trusted on these particular voyages were often considered good

118 George Fisher to Francis Beaufort, Greenwich Hospital, 7 March, 1836. TNA, ADM1/4614

119 George Fisher, Navigational Workbook: Workings of Chronometers, Greenwich(?) and New York. NMM, FIS/22

120 Papers on clock and chronometer improvements, 1836-1844. CUL, RGO 6/585

enough for navigation in general. It was their specific use in the pursuit of knowledge that led to these procedures of improvement.

This chapter has detailed the procedures that officers put in place to prevent chronometers from behaving poorly or breaking down at sea. It also showed how they learned to deal with them in different circumstances. But more often than not, error was not evident through examining the instruments alone, only through constant monitoring and examination of the data produced. All chronometers deviated, some more than others. At some point, trust in the instrument would fail, but it was up to users to decide when this moment arrived. Decisions made on the basis of the comparison tables were directly related to the rating of the chronometers, which always involved astronomical methods. It was when rating chronometers that they interacted with other instruments and methods, and this aspect of chronometry at sea is examined in the following chapter.

6

Keeping Track

> [S]hips tracks would then be laid down with far greater accuracy & current would in consequence be estimated; a degree of precision hitherto unknown would belong to those occasional surveys which officers have it so often in their power to undertake; a taste for nautical research would soon follow, & it might reasonably be expected that, in a few years a much more scientific habit of navigating ships would become general, than can ever obtain under the present state of things.[1]

Introduction

Basil Hall wrote the above at a time in which chronometers use at sea was increasing.[2] He urged the Admiralty to supply at least ‘one good chronometer’ to each Royal Navy vessel, believing that this would ‘considerably’ increase their security and result in financial benefits. But Hall’s argument went further. Hall thought the chronometers should be supplied by the Admiralty, as they could judge the merits of each individual instrument, through trials at the Royal Observatory (see Chapter 3). He continued to point out that captains not supplied with chronometers were limited to a record based only on the log board (as used for keeping account of the ship by dead reckoning) in their navigational accounts. Another problem was due to the difficulty in rating chronometers; that was already apparent on shore:

> It is well known that the rates furnished by the makers cannot de depended on. And those given at the naval college, or by any of those persons who undertake this task at the sea ports, are liable to a similar criticism. The reason of this is perfectly clear to every person conversant with the subject; because it is certain that to rate even <u>one</u> chronometer with the proper degree of precision, a great deal of pains & exclusive attention are indispensable: when a <u>number</u> are to be rated it is absolutely impossible that it can be done by any man, let his talents or industry be what they may.[3]

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[1] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956
[2] Yuto Ishibashi, ‘A Place for Managing Government Chronometers: Early Chronometer Service at the Royal Observatory Greenwich’, *The Mariner's Mirror*, 99, (2013), pp. 52-66
[3] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956

Without attending to the particulars of rating chronometers, Hall 'considered half the advantage of the instrument [was] lost'. In addition to the navigational benefits he envisioned not only that an officer would be enabled 'to do his duty much better', but also that it would 'furnish the admiralty with the means of ascertaining exactly how far the proper degree of attention had been paid to the navigation of the ship'.[4] This could be achieved by each captain sending an account of the performance of each chronometer alongside 'a chart & such other notices as might be deemed necessary' to a central depot. For Hall, this report would achieve three goals that went beyond just judging the merits of a single instrument. Judging the performance of the instruments was Hall's first aim. He also believed this practice would lead to better habits among officers, to 'stimulate the zealous & well informed to fresh exertions, & new attainments, & it would to a certain extent compel the indolent & ignorant to attend to subjects which, however useful, would otherwise have occupied very little of their thoughts'. Finally, Hall claimed it would give 'the admiralty a very fair & ready means for getting at the character of officers, in a most essential particular'.[5]

To understand what Basil Hall had in mind when he wrote thus to the Admiralty, we need to understand a number of elements of early nineteenth-century navigation involving chronometry. The title of this chapter, 'Keeping Track', refers to three aspects of chronometry which are critical to understanding the chronometer and how its use evolved in the context of these scientific expeditions and which are examined in what follows. Keeping track refers to the ship's track on the ocean, in the general sense of its navigation: officers had to keep track of where they were and where they were heading. It relates also to keeping track of the rate and error of the chronometers, to determine which instruments were reliable and which corrections were required to the data they produced. Keeping track

[4] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956
[5] Ibid

finally and additionally relates directly to the data produced: the process of selecting, sorting, documenting and imposing order on chronometric data, or, 'keeping the books'.[6] The latter two aspects reveal how observatory techniques became embedded within Royal Navy practice. These techniques included the 'calibration, manipulation, and coordination of precision instruments for making observations and taking measurements'.[7] Like astronomers and their assistants in the observatory, naval officers had to learn the methods of 'data acquisition, reduction, tabulation, and conservation, along with complex mathematical analyses'.[8]

In his work on images in the sciences, Hentschel stresses that, 'it would be a mistake to analyze any scientific or technological image in artificial isolation from its context of foregoing images and from the cultural tradition in which that image arose'.[9] The same sentiment applies to the marine chronometer and its use at sea. Chronometers functioned within cultural and social traditions that we cannot ignore. The chronometer was situated within traditional practices of maritime navigation, and it complemented methods and procedures already in use. Bennett has shown how the 'navigational competence' of East India Company officers affected the development of lunar distances.[10] But the emergent group of scientific naval officers (detailed in Chapter 4), engaged in scientific expeditions on board Royal Navy voyages, were moulding these practices to fit their needs. Hall's aim was

[6] Simon Schaffer, 'Keeping the Books at Paramatta Observatory', in: *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture,* David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), pp. 118-47

[7] David Aubin, Charlotte Bigg, H. Otto Sibum, 'Introduction: Observatory Techniques in Nineteenth-Century Science and Society', in: *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture*, David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), p. 6

[8] Ibid, p. 7

[9] Klaus Hentschel, *Visual Cultures in Science and Technology: A Comparative History*, (Oxford: Oxford University Press, 2014), p. 133

[10] Jim Bennett, 'Mathematicians on board: introducing lunar distances to life at sea', *British Journal for the History of Science*, 52, (2019), p. 65

to extrapolate the practices on board these voyages to surveyors and then into generalised navigational practice.

What Hall wished to achieve was a regulated and standardised practice so that all navigators could contribute data. Whilst scientific naval officers were seen as authorities with the social standing and moral judgement to determine the reliability of their own practices, others were not. It was in the hands of these others that standardisation was thought necessary. This could only be achieved through discipline, as ‘disciplines give meanings to values, and often resist attempts by others to redefine these meanings or to gain authority over measurement’.[11] It is perhaps impossible to discuss these developments without mentioning Alexander von Humboldt, the Prussian geographer and explorer who ‘helped to establish international networks of observers to collect similar data from around the world’.[12] As an admirer of Humboldt, Hall attempted to achieve the same in navigation. For Hall, this would improve navigation to a degree that would have both economic and safety benefits, but more importantly, it would also aid other explorers in their endeavours to create authoritative knowledge about the world. Humboldt’s approach to observation and measurement is relevant here if we follow Tresch’s observation that to produce objective knowledge, rather than eliminate observers, Humboldt sought to multiply them and thus achieve objectivity through ‘interdependence, mediation and community’.[13] Humboldt aimed to ‘enhance interdisciplinary analysis through the use of mathematics and statistics’.[14]

[11] Simon Schaffer, ‘Astronomers Mark Time: Discipline and the Personal Equation’, *Science in Context*, 2, (1988), p. 115
[12] John Tresch, ‘Even the Tools will be Free: Humboldt’s Romantic Technologies’, in: *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture,* David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), p. 255
[13] Tresch, ‘Even the Tools will be Free’, p. 257
[14] Anne Marie Claire Godlewska, ‘From Enlightenment Vision to Modern Science? Humboldt’s Visual Thinking’, *Geography and Enlightenment,* David N. Livingstone and Charles W. J. Withers, eds. (Chicago: The University of Chicago Press, 1999), p. 237

This chapter, and that following, will focus in particular on the chronometric data produced by these voyages. This numerical data, although at first glance seemingly indecipherable, reveals in depth what day-to-day chronometry was all about. Here, I will show how, by focusing on calculations of a particular longitude, we can understand exactly *how* longitude determinations were made ‘in the wild’ and tied up with other instruments and methods. In addition, by cross-examining and comparing the various numerical documents produced, I shed more light on the importance of data management and I examine how most of the chronometric determinations were a result of this process, rather than on-the-spot readings of these instruments.

The first section examines the ship’s track and how this was constructed, or kept, by officers based on their determinations of latitude and longitude. To assume that a ship’s track was merely a record of its latitudes and longitudes, brought together on a chart, however, misses a vital point: these coordinates were dependent on many actors, involving the ship, officers, multiple instruments, and observations taking place in time and space. They were never really ‘on-the-spot’ determinations, but were themselves constructed through a continuous process of multiple observation, measurement, plotting, and backtracking. Not until 1843, when American merchant Captain Thomas Hubbard Sumner published a method that became known as position line navigation, could latitude and longitude be calculated simultaneously.[15] The chronometer was only one part of this navigational network that was shaped, tracked and connected through the ship’s constant interaction with the coastline. The ship, as Sorrenson proposed, not only transported observers and instruments, but also

[15] Guy Boistel, ‘Training Seafarers in Astronomy: Methods, Naval Schools, and Naval Observatories in Eighteenth- and Nineteenth-Century France’, translated by David Aubin and Charlotte Bigg, in: *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture*, David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), pp. 148-173

‘shaped the kinds of information observers collected’.[16] Chronometry did not stop when an officer read and noted the time off the dial. This ‘raw data’ required considerable processing to transform it into useful knowledge.

The second section examines how officers kept track of the performance of each chronometer and how they dealt with, mitigated and managed error. Building on what we have seen in the previous chapter, I examine how the chronometers were monitored using comparison tables and what steps were involved in ascribing a rate to each chronometer. On these expeditions this work was rather more complex than it may have been on voyages where chronometers were used for more general navigational purposes, where officers would use the rate as determined by the makers, an astronomer or through their own observations pre-departure until their destination was reached.

Chronometry involved the production of lots of data. This was often produced on loose sheets, computed in observation books and collected in navigational notebooks by various officers. Order had to be imposed on this data. When we examine the final processed data produced by these voyages, it is often in the form of a list of longitudes according to place, a noon longitude in a logbook or the longitude and latitude of a pendulum station. Officers would keep the processed data to serve as evidence for their determinations, often in tabulated numerical form, discarding the process of selection that led to these outcomes. These techniques used at sea, of generating, tabulating and manipulating data, were later used by statisticians ‘with the goal of making them universally comparable [and] bear close resemblance to those designed by observatory scientists’.[17] By applying the same methods and procedures that were used in observatories, this ensured that ‘measurement, numbers,

[16] Richard Sorrenson, ‘The Ship as a Scientific Instrument in the Eighteenth Century’, *Osiris*, 11, (1996), p. 227
[17] Aubin, Bigg, and Sibum, ‘Introduction: Observatory Techniques in Nineteenth-Century Science and Society’, p. 13

and statistics [allowed] a certain transferability of data and analysis across fields'.[18] This data, collected centrally at the Hydrographic Office, aided the Hydrographer in compiling lists of the latitude and longitude of distant places. These coordinates in turn assisted those mapping other geographical knowledge such as terrestrial magnetism, geodesic measurements, tides and currents.[19]

Chronometers not used in isolation

Chronometer use was shaped not only by the limitations of the instrument, the training and aims of the captain and officers, but also by existing practices of navigation. Scientific naval officers experimenting with chronometers and astronomical observations worked in collaboration with the master and mate charged with the traditional tasks of dead reckoning. Over time, the practices of these different groups merged, so shaping new practices. For Miller, 'neither technological determinism identifying an instrument as *the* solution, nor singular method determinism, captures how longitude was established in practice'.[20] Longitude was determined in a multitude of ways, often a singular point of longitude was never an 'on-the-spot' determination by an instrument or method alone, but a collaboration of officers, procedures, instruments and measurements.

Yet it was common within navigational literature to find the various methods for finding longitude to be listed chronologically or by technology. In such descriptions, latitude and longitude are identified as two different entities. The divide goes even further: longitude can be found by observations of Jupiter's Satellites, the Moon's occultations, eclipse

[18] Godlewska, 'From Enlightenment Vision to Modern Science? Humboldt's Visual Thinking', p. 245
[19] John Cawood, 'The Magnetic Crusade: Science and Politics in Early Victorian Britain', *Isis,* 70, (1979), pp. 492-518
[20] David Phillip Miller, 'Longitude Networks on Land and Sea', *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds. (Basingstoke: Palgrave Macmillan, 2016), p. 224

observations, dead reckoning, lunar distances, or by chronometer. Of these, only the last three could be adopted at sea. The first three could only be performed onshore, and often required the instruments and expertise of astronomers, the setting-up of a temporary observatory, and extensive tables to correct the observations. The methods also differed in another way: astronomical observations 'find', or determine longitude, while the chronometer and dead reckoning 'kept' longitude. Hipparchus long ago suggested the use of astronomical observations such as lunar eclipses to find longitude but not until the theory of the motion of the Moon was further developed during the seventeenth century were lunar eclipses reliably used. Galileo's insight that Jupiter's Satellites could prove useful had to wait for seventeenth-century developments to be practically applicable. John Flamsteed made significant contributions to astronomical methods during his forty-four years as Astronomer Royal, as did his successor Nevil Maskelyne.[21] Navigators using the *Nautical Almanac* by the late eighteenth- and early nineteenth century drew on this data and calculated predictions for most of their observational calculations. As such, observatory work was never far from the sea and the practices carried out on board ships.

Whilst the chronometer was in development, methods and instruments for dead reckoning, lunar distances and latitude were also progressing. Tables of refraction, parallax, sines, secants and logarithms improved. Errors in the tables were addressed and corrected.[22] Each year, new data for the Moon's position for the years ahead were being published. Massey's patent log was developed and the sextant refined.[23] All these developments took place on land and substantial amounts of observational data were gathered at Greenwich

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[21] Albert Van Helden, 'Longitude and the Satellites of Jupiter', in: *The Quest for Longitude*, William J. H. Andrewes, ed. (Harvard University: Collection of Historical Scientific Instruments, 1996), pp. 85-100
[22] Anonymous, "XII. On errors in the nautical almanac, &c.", *The Philosophical Magazine*, 48, (1816), pp. 34–35.
[23] Jim Bennett, *Navigation: A Very Short Introduction*, (Oxford: Oxford University Press, 2017), pp. 98-99; W. E. May, *A History of Marine Navigation*, (Henley-on-Thames: G T Foulis & Co, 1973), p.115; Charles H. Cotter, *A History of Nautical Astronomy,* (London: Hollis & Carter, 1968), pp. 87-92

and at observatories overseas. Explorers and surveyors collected and published data measured 'in the field in various parts of the globe. This data included positions of latitude and longitude, and information concerning refraction, parallax and the speed of sound in different latitudes. All these instruments, tables, accounts, calculations and publications were taken on board the next voyage setting out. In practice, determining longitude was a rich, varied and multi-layered process.

What follows examines a particular determination of longitude made by Parry and Sabine in 1819, based on extant sources that document practice on board the *Hecla*. This example has been chosen as the astronomical work book in which Sabine recorded the calculations, Sabine's chronometer journal, and the detailed published appendix have all survived. Examining the data sheds light on the methods and procedures pursued. This gives us unique insight into how the chronometric longitude of 24°10'14" determined at noon on 27 May 1819 was actually established in practice.

Sabine kept an observation book to determine the latitude and the chronometric longitude for 1819 and 1820.[24] It contained the tabulated data that Parry printed in the appendix to his *Journal*. In the *Journal,* two longitude determinations are shown, the first by the standard (P&F 228), the second the 'longitude corrected', the mean of six chronometers selected for these determinations. In the manuscript book, Sabine explained that 'The latitudes in common ink were observed; those in red ink were deduced from the (transit) observed; so also the longitudes in common ink are the results of the elements which accompany them, and those in red ink are the observations of the day carried to noon by the reckoning'.[25] By highlighting the determinations noted in red ink found in the manuscript

[24] Abstract of observations to determine the latitude, and the longitude by chronometers, 1819 and 1820; TNA BJ 3/61
[25] Chronometers: Determination of latitude and longitude. TNA, BJ 3/61

material onto the published table in the appendix, the relationship between the latitude and longitude becomes apparent (figure 6.1).[26]

LATITUDES, AND LONGITUDES BY CHRONOMETERS, *continued.*

1819	Time by 228	228' correction to mean Greenwich time	Observed Altitude	Dip of horizon	Observer	Apparent time	Latitude	Longitude By 228	Longitude By six Chronometers	REMARKS
	H M S	SLOW m s	° ′ ″	′ ″		H M S	° ′ ″	° ′ ″	° ′ ″	
May 30	21 56 04.5	2 41	33 51 36 L	4 04	H	19 59 26.5	58 14 0 N	30 31 55 W	30 36 05 W	
31	....	....	....	...	..	noon	....	30 51 48	30 55 58	
June 1	23 23 23.4	2 42.1	43 14 29 L	4 00	P	21 10 12.6	57 05 00	34 35 59	34 40 44	
2	....	....	....	...	P	noon	57 00 38	34 39 39	34 44 24	
,,	22 35 12.2	2 42.7	37 23 59 L	4 00	B	20 19 40	56 04 42	35 09 13	35 14 15	
,,	23 48 00.6	2 42.7	46 33 57 L	3 37	P	21 32 58.7	56 01 45	35 01 35	35 06 37	
3	....	....	....	...	P	noon	55 57 51	35 02 41	35 07 43	
,,	23 33 07	2 43.3	45 03 05 L	4 00	S	21 14 57.3	55 05 30	35 46 20	35 51 22	
,,	23 37 02.2	2 43.3	45 29 20 L	4 00	H	21 18 24.9	55 04 21	35 53 10	35 58 12	
4	....	....	....	...	P	noon	55 00 33	35 54 00	35 59 02	
,,	21 39 46.75	2 43.8	29 37 57 L	3 56	H	19 21 09.1	55 02 55	35 51 06	35 56 16	
,,	21 50 44.85	2 43.8	31 11 27 L	4 00	B	19 32 01	55 04 30	35 52 45	35 57 55	
,,	22 18 46.7	2 43.8	35 09 07 L	4 00	P	20 00 00	55 02 00	35 53 21	35 58 31	
,,	22 24 29	2 43.8	35 56 32 L	4 00	S	20 05 38	55 01 03	35 54 20	35 59 30	
,,	22 35 39.45	2 43.8	37 28 52 L	4 00	H	20 16 45.4	55 03 07	35 55 10	36 00 20	
5	....	....	....	...	..	noon	....	36 10 21	36 15 31	
6	....	....	57 04 50 L	4 20	S	noon	55 21 22	37 23 09	37 28 24.3	
,,	7 13 36.6	2 44.4	28 17 14 L	4 10	S	4 49 05	55 31 04	37 14 00	37 19 15	
,,	7 24 18.25	2 44.4	26 46 57 L	4 0	B	4 59 42.5	55 32 57	37 17 17	37 22 32	
,,	22 05 43.5	2 45	32 39 50 L	3 50	S	19 41 57	55 49 07	37 03 30	37 08 50	
,,	22 18 37.8	2 45	34 23 34 L	3 36	H	19 54 25.7	55 48 16	37 09 51	37 15 11	
,,	22 19 21	2 45	34 42 00 L	3 40	B	19 55 17	55 46 13	37 07 45	37 13 05	
7	....	....	....	...	P	noon	55 51 13	37 12 22	37 17 42	
8	....	....	....	...	P	noon	56 26 57			
,,	22 33 07.8	2 46	36 14 14 L	4 00	H	20 07 11.9	55 06 53	37 30 20		
,,	22 44 57.2	2 46	37 50 56 L	3 33	B	20 19 09	56 07 14	37 28 33	37 34 59.7	
,,	23 25 51.3	2 46	43 09 54 L	3 30	P	20 59 55.6	56 03 00	37 29 39		
June 9	....	.....	56 48 30 L	4 00	S	noon	55 54 48	37 31 17	37 36 42.7	
,,	6 53 07	2 46	31 44 23 L	3 55	S	4 26 00	55 45 00	37 47 15		
,,	7 17 42.9	2 46	28 18 13 L	3 53	H	4 50 31.2	55 43 05	37 48 36		
,,	7 26 53.4	9 46	26 59 47 L	3 40	P	4 59 47	55 42 00	37 46 06	37 52 49.7	
,,	7 29 30.6	2 46	26 28 21 L	3 33	B	5 02 22	55 42 49	37 47 39		
,,	21 57 24.5	2 46.7	31 06 22 L	3 50	P	19 29 03	55 46 00	38 04 29	38 08 31	
,,	21 59 43.6	2 46.7	31 26 00 L	3 37	B	19 31 33	55 46 30	38 01 36		
,,	22 17 02	2 46.7	33 49 27 L	3 47	S	19 48 40	55 46 33	38 04 25	38 09 00	
,,	22 23 32.8	2 46.7	33 44 28 L	3 44	H	19 55 17.9	55 46 50	38 02 34		
10	....	.....	56 50 55 L	4 00	S	noon	55 57 25	37 56 31.5	38 02 03.75	
,,	7 09 44.6	2 46.7	29 32 27 L	3 33	B	4 42 00.5	56 08 20	37 53 51		
,,	7 12 27.1	2 46.7	29 10 01 L	3 57	H	4 44 45	36 08 20	37 53 22	37 59 09.25	
,,	7 16 32.4	2 46.7	28 35 45 L	3 37	P	4 48 49.2	56 08 15	37 53 39		
11	....	.....	....	...	P	noon	56 29 50	40 00 00	40 05 38	
,,	5 10 02.55	2 47.3	46 17 43 L	4 00	S	2 33 04.7	56 34 06	40 09 47	40 15 25	
,,	6 40 27.1	2 47.3	34 53 08 L	3 40	P	4 03 05.3	56 37 30	40 15 33		
,,	7 14 07.2	2 47.3	30 18 40 L	3 56	H	4 36 42.4	56 39 00	40 16 41	40 22 22	
,,	7 14 43.5	2 47.3	30 14 12 L	3 33	B	4 37 12	56 38 45	40 17 57		
,,	23 32 27.4	2 47.8	42 03 40 L	3 30	P	20 53 53.7	57 18 15	40 31 25	40 37 19	
,,	23 37 02.4	2 47.8	42 37 00 L	4 11	B	20 58 28	57 19 32	40 31 50		
,,	24 07 39.3	2 47.8	46 11 54 L	4 06	H	21 29 27.9	57 19 03	40 25 57	40 31 39	
12	....	.....	....	..	P	noon	57 23 09	40 28 20	40 34 02	
13	....	.....	....	...	P	noon	57 50 24	40 44 30	40 50 13.5	
,,	6 39 42.6	2 48.4	35 10 49 L	3 50	B	3 59 38	57 55 00	40 50 20	49 57 03	
,,	7 10 35	2 48.4	31 09 45 L	4 10	S	4 30 23	57 56 00	40 52 21		
,,	21 39 57.6	2 49	26 58 14 L	4 12	B	18 57 46	57 42 50	41 20 30	41 26 08	
,,	22 21 15.1	2 49	32 25 35 L	4 00	P	19 38 54.3	57 41 40	41 22 51	41 28 29	
,,	22 32 28.9	2 49	33 55 21 L	4 08	H	19 50 06	57 42 13	41 23 10	41 28 48	
,,	23 33 56	2 49	41 40 48 L	4 10	S	20 51 08.5	57 40 52	41 29 15	41 34 53	
14	....	.....	55 26 50 L	3 40	S	noon	57 37 16	41 41 50	41 47 28.5	
,,	8 09 14.1	2 49	24 04 41 L	3 40	S	5 23 53.65	57 30 00	42 06 20	42 11 59.8	
,,	8 11 06.95	2 49	23 49 57.6 L	4 00	B	5 25 46.5	57 30 00	42 06 20		

Figure 6.1: Parry's *Appendix to his Journal.* I have used Sabine's Journal (TNA, BJ3/61) to identify the latitudes and longitude deduced from the reckoning. These are highlighted in red.

[26] The red ink has deteriorated faster than the common ink used, and is becoming illegible; but comparison with the published appendix show the results are the same.

This demonstrates how latitude determined astronomically by the noon observation of the Sun always required dead reckoning to connect it to a particular determination of longitude. Similarly, the longitude, as determined by the altitude of the Sun in the evening or morning, required dead reckoning to connect it to the latitude determined at noon. This is corroborated by Sabine's astronomical notebook, which contains the calculations for the determinations which were made by Sabine.[27] Figure 6.2 shows Sabine's observation for 27 May 1819. It contains calculations for the determination of longitude by chronometer; observations and calculations to determine the variation of the compass; comparisons between chronometers to determine a mean longitude and an explanation of some soundings taken on that day.

The sections relating to the longitude on the page can be summarised as follows (the boxes drawn around the original material correspond to the descriptions below):

1. Noon observations for latitude.
2. Correction for longitude by dead reckoning.
3. Astronomical observations and calculations to determine local Mean Time and Greenwich Mean Time by chronometer P&F 228.
4. Noon longitude calculated by each chronometer.
5. Noon longitude by the mean of six chronometers on May 27th 1819.
6. Recalculation of the longitude by chronometer P&F 228, based on the new rates determined by the lunar observations taken in June and August 1819.
7. Noon longitude in time by P&F 228 based on the mean of four observers.
8. Noon longitude recalculated for each chronometer based on the new rates determined by the lunar distances.
9. Longitude by P&F 259 based on the new rates.
10. Corrected noon longitude by the mean of six chronometers. Corrected by dead reckoning to noon and by lunars for the rates.

[27] Edward Sabine, HECLA voyage: observations 1818-1819. TNA, BJ3/58

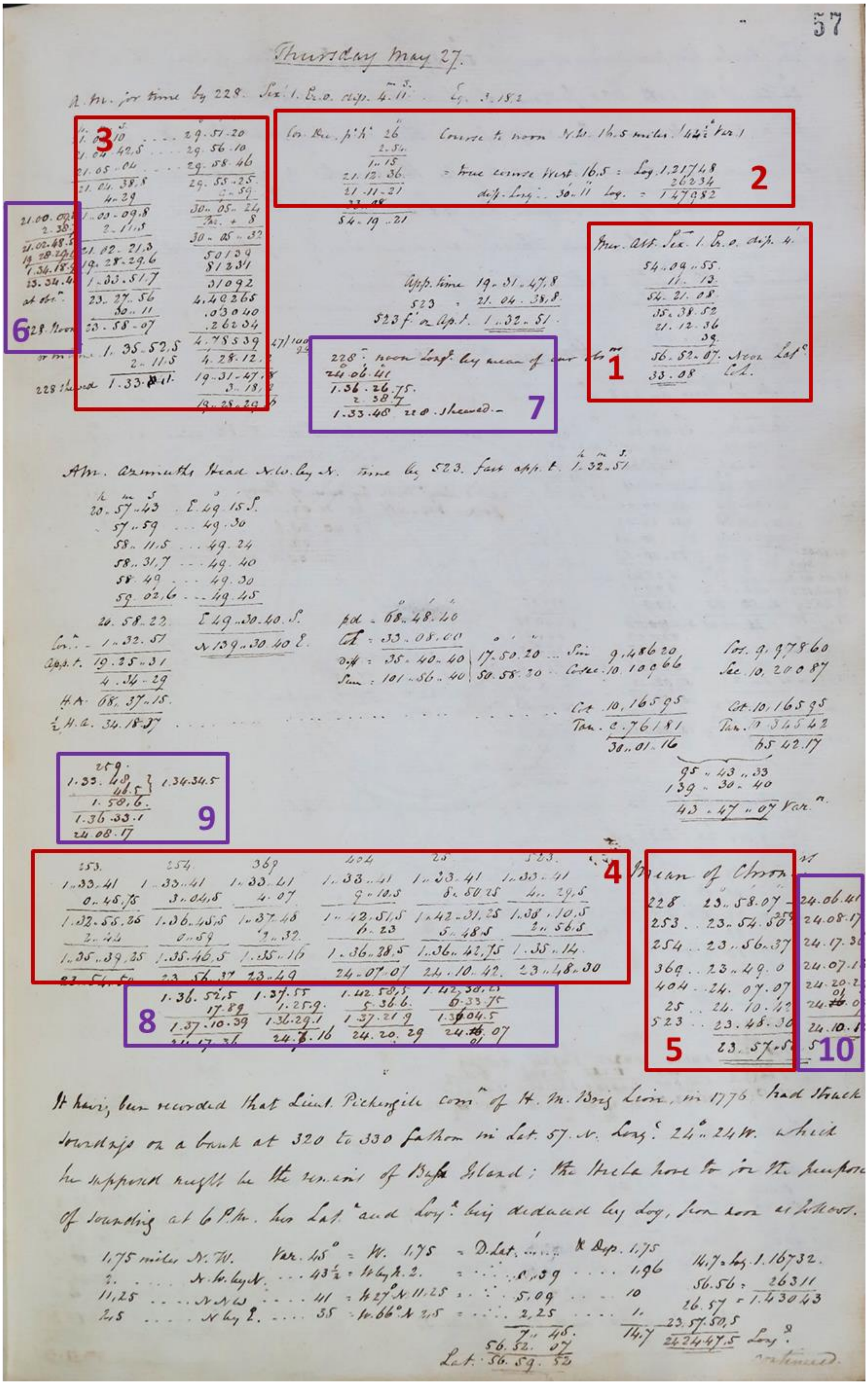
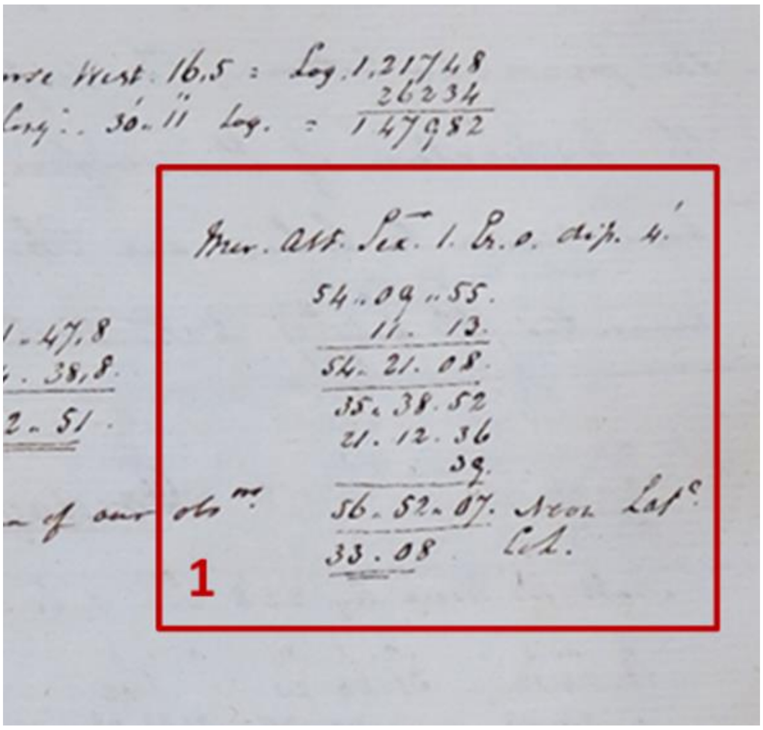


Figure 6.2: Sabine's astronomical observations, 27 May, 1819. TNA, BJ3/58

The steps indicated in red were those determined on 27 May 1819, those indicated in purple are recalculations from a later date.

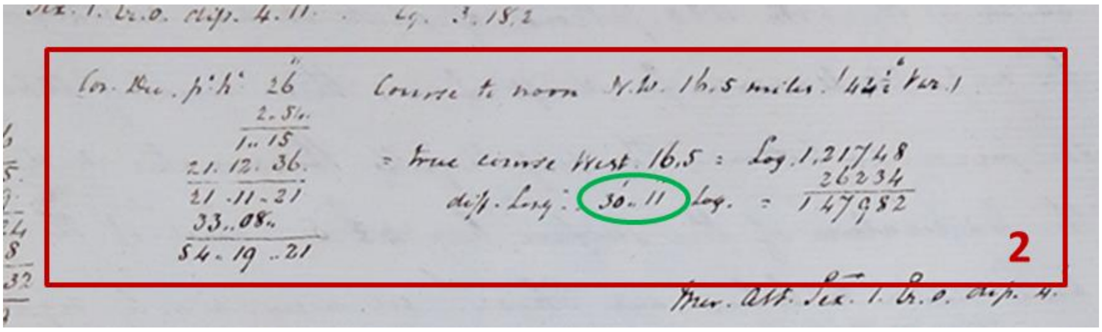
1. Noon observations for latitude.



This is the observed meridian altitude of the Sun with corrections to determine the latitude at noon. Sabine corrected the observed altitude for dip (4’), refraction, semi-diameter and parallax (11.13). A correction for index error was not necessary, as Sabine had set the index error of his instrument to zero. Using the principles of spherical trigonometry and the tables containing the values for the Sun’s declination, Sabine observed, corrected and calculated their latitude at noon.

2. Correction for longitude by dead reckoning.

The latitude was corrected by the course and distance as determined by the log account. What Sabine needed was the meridian altitude of the sun at the *place* where the observations for time had been made. This correction enabled Sabine to establish what the meridian altitude of the Sun *would* have been at the ship’s position during the altitudes taken for local time and thus the difference in longitude between the two observations. Had the *Hecla* been stationary, this step would not have been necessary.


Course to noon N.W. 16.5 miles

= true course West 16.5 : Log 1.21748

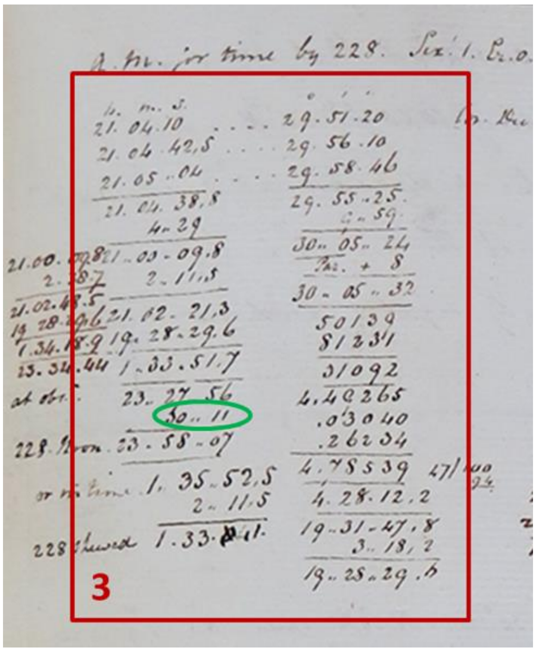
26234

dep. Long: 30..11 Log. = 1.47982

2

3. Astronomical observations and calculations to determine local Mean Time and Greenwich Mean Time by chronometer P&F 228.

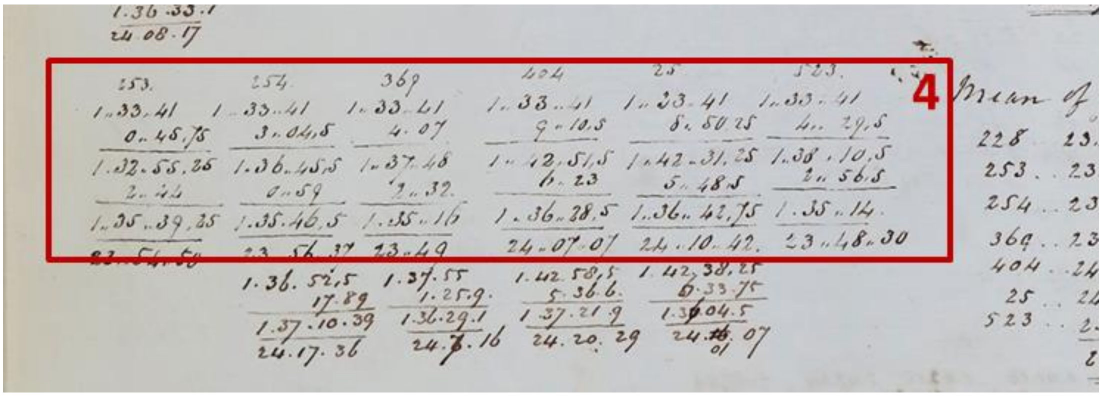
21.04.38,8	Mean Time of observation by 523
- 4.29	Difference between 228 and 523
21.00.09,8	Time of observation by 228
+ 2.11,5	Correction for rate and error
21.02.21,3	Corrected time of observation
19.28.29,6	Established local Mean Time
1.33.51,7	Difference of longitude in time
23.27.56	Difference of longitude at observation
+ 30.11	Correction longitude to noon
23.58.07	Longitude at noon by 228
1.35.52,5	Longitude at noon in time
- 2.11,5	Correction for rate and error
1.33.41	Time shown by 228 at noon for observation


3

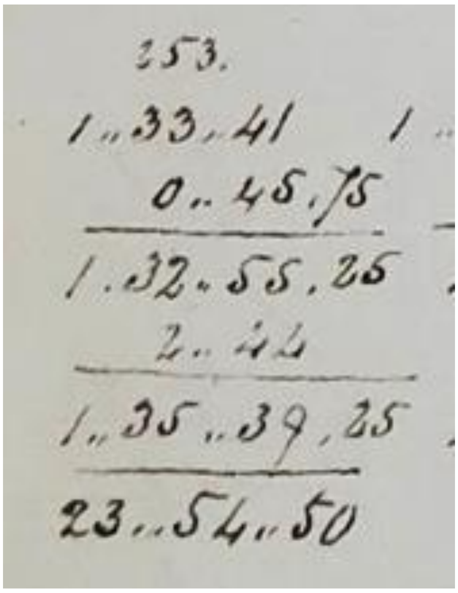
In step 3, the calculation for longitude is given in the left-hand column. The calculation for the ship's local time is in the right-hand column. For the ship's local time, Sabine noted the mean of his three meridian observations and corrected this for dip, refraction and parallax to determine the true altitude. As with latitude, Sabine relied on the principles of spherical trigonometry and extracted relevant data from the tables. The established local Mean Time can be found at the bottom of the right-hand column: 19h28m29.6s. The left-hand column shows how Sabine determined the Greenwich Mean Time based on the chronometer (Arnold 523) that recorded the time of the observations. By comparing Arnold 523 with the standard, namely P&F 228, Sabine calculated the time of observation by the standard. The standard was then corrected for rate and error, which were extracted from the comparison tables. The difference between this corrected time and the local Mean Time, as established in the right-hand column, was the difference in longitude at the place of the observations. Using the difference in longitude between the place of the noon observations and the morning observations, Sabine then corrected the longitude to noon, by adding the distance sailed according to the dead reckoning (30’11”). The result was the longitude at noon, according to the standard chronometer P&F 228 (23°58’07”). Sabine then needed to compare the standard chronometer to the other chronometers and thus required the time shown by the standard at the time of the noon observation (which was taken by Arnold 523) to compare it to the other chronometers. Sabine thus established the noon longitude by P&F 228 in time rather than degrees (23°58’07” is 1h35m52.5s in time). By subtracting the rate and error, Sabine determined what chronometer P&F 228 would have shown at the time of the noon observations for latitude: 1h33m41s. Having this data allowed Sabine to use the noon comparison table to determine the time of the noon observation by each chronometer.

4. Noon longitude calculated by each chronometer.

Sabine also required the longitude at noon for each of the other chronometers which warranted the following steps. He compared the time calculated for P&F 228 (1h33m41s) to all the other chronometers, using the table of the noon comparison.



For each chronometer, the calculation was as follows:



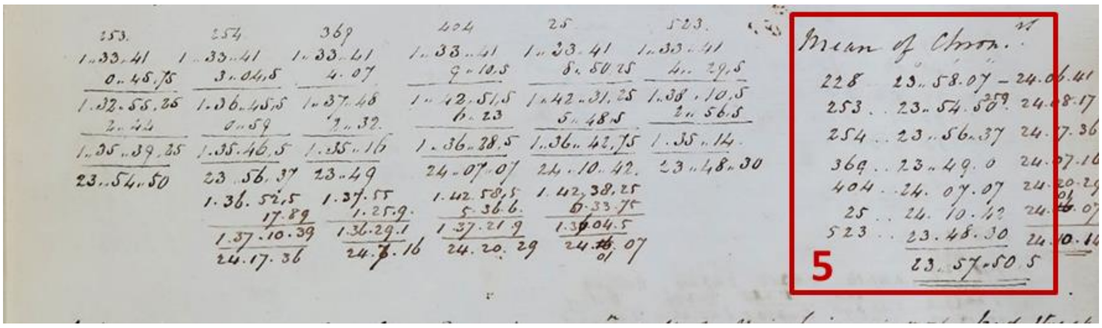
Chronometer P&F 253

1.33.41	Time at noon by P&F 228
- 0.45,75	Difference between P&F 228 and P&F 253
1.32.55,25	Time of noon observations by P&F 253
+ 2.44	Correction for rate and error for P&F 253 based on the Greenwich rates.
1.35.39,5	Longitude in time by P&F 253 at noon, May 27th 1819
23.54.50	Longitude in degrees by P&F 253 at noon, May 27th 1819

Sabine used the noon comparison table to determine the time shown by each chronometer at noon. He did this by adding or subtracting the difference between P&F 228 and each chronometer as noted by the noon comparison. By doing so, Sabine calculated what each chronometer would have shown at the time of the noon observations, in relation to chronometer P&F 228. This was then corrected for the rate and error of each chronometer. As the correction for the rates and errors was dependent on those established upon departure, P&F 259 was not included in these initial determinations as it had been delivered only days before the expedition sailed.

5. Noon longitude by the mean of seven chronometers on 27 May 1819.

Having calculated the noon longitude for each chronometer, Sabine then determined the mean longitude by six chronometers.

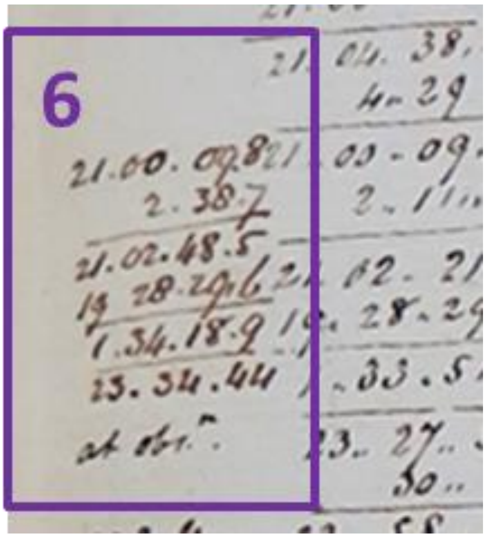


In this calculation, the longitude was 23°57’50”5 west by chronometer numbers 228, 253, 254, 369, 404, 25 and 523.

6. Recalculation of the longitude by chronometer P&F 228, based on the new rates determined by the lunar observations taken in June and in August 1819

Sabine based these calculations on the temporary rates assigned to each chronometer on departure. During June and August, Parry, Beechey, Hooper, Ross and Sabine observed a total of 1209 lunar distances, 640 in June, 569 in August. Sabine recalculated the rates for each chronometer twice based on these observations. Initially, interim rates were given to each chronometer in August, when Sabine received observations from each observer. Sabine corrected these in the following winter, as ‘in their computation the mean refraction of the tables had not been in all instances corrected for variations in temperature and atmospherical pressure’.[28] These rates were again confirmed by 6862 lunar distances taken on land on the coast of Melville Island.

[28] William Edward Parry, *Journal of a Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific Performed in the Years 1819-20, in His Majesty’s Ships* Hecla *and* Griper*,* (London: John Murray, 1821), Appendix, p. xxxiii

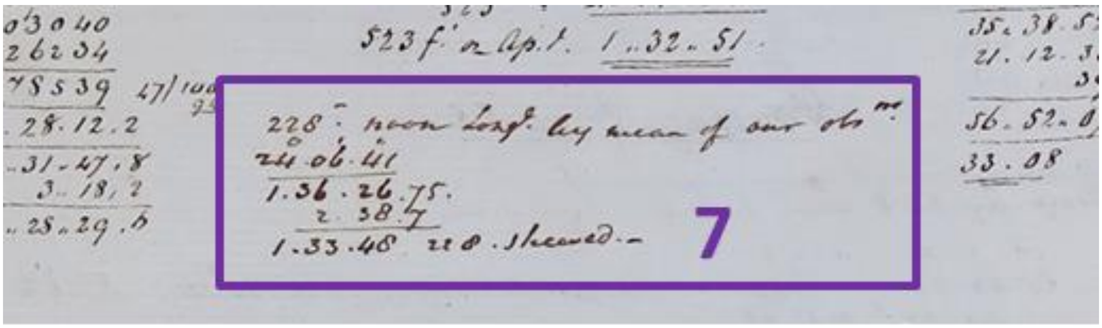


21.00.09,8	Time of meridian observation by 228
2.38,7	Corrected rate by Lunars
21.02.48,5	Corrected time for observation by 228
19.28.29,6	Local Mean Time
1.34.18,9	Difference in time
23.34.44	Difference in longitude

A new longitude of 23°34’44” at the place of observations was the result of this calculation.

7. Noon longitude in time by P&F 228 based on the mean of four observers.

This is the same calculation that Sabine performed in step 3, where he calculated what the standard chronometer would have shown at noon. Sabine translated the longitude in degrees into a longitude in time (24°06’41” in time is 1h36m26.75s) and removed the correction for rate and error to get the time of P&F 228 at the noon observation. As Sabine had done earlier, he could compare this data with the noon comparison to get times from the other chronometers.



One detail of these calculations not included on this page is how Sabine determined the longitude to be 24°06’41”, rather than the 23°34’44” he calculated in step 6.

To understand the corrections made to these initial determinations we need to look at another document produced by Sabine on this voyage. This small bound volume contains pre-printed forms for the calculation of longitude.

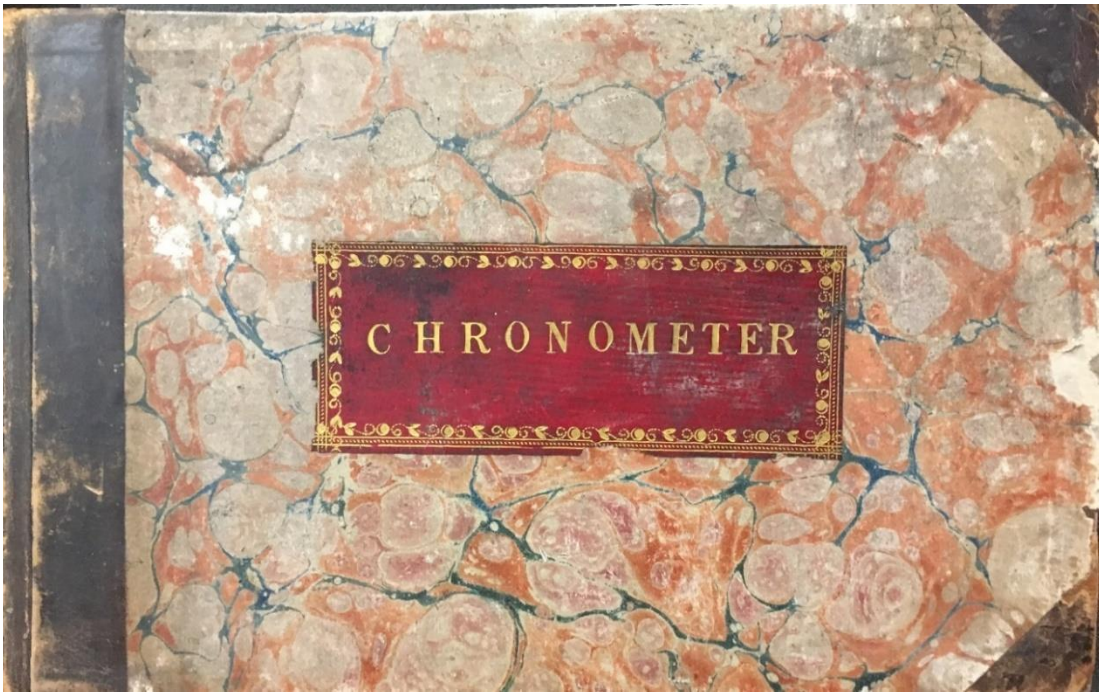


Figure 6.3: Front cover of Sabine's Chronometer Book. TNA, MS/831

On these pages, Sabine filled out the altitudes and times by which they were observed; the corrections for dip, refraction, parallax and semi-diameter; the computations for calculating the local time and the resulting longitude based on the difference with the time by chronometer. On the blank pages, Sabine sometimes added additional information, often, but not always, relating to the longitude. This is not a document that recounts every determination of longitude made during the voyage. Most of the entries are for August and September; there are five entries for May, four for June and July. It is not clear why these dates were significant for Sabine. The page for 27 May 1819 appears below (figure 6.4).

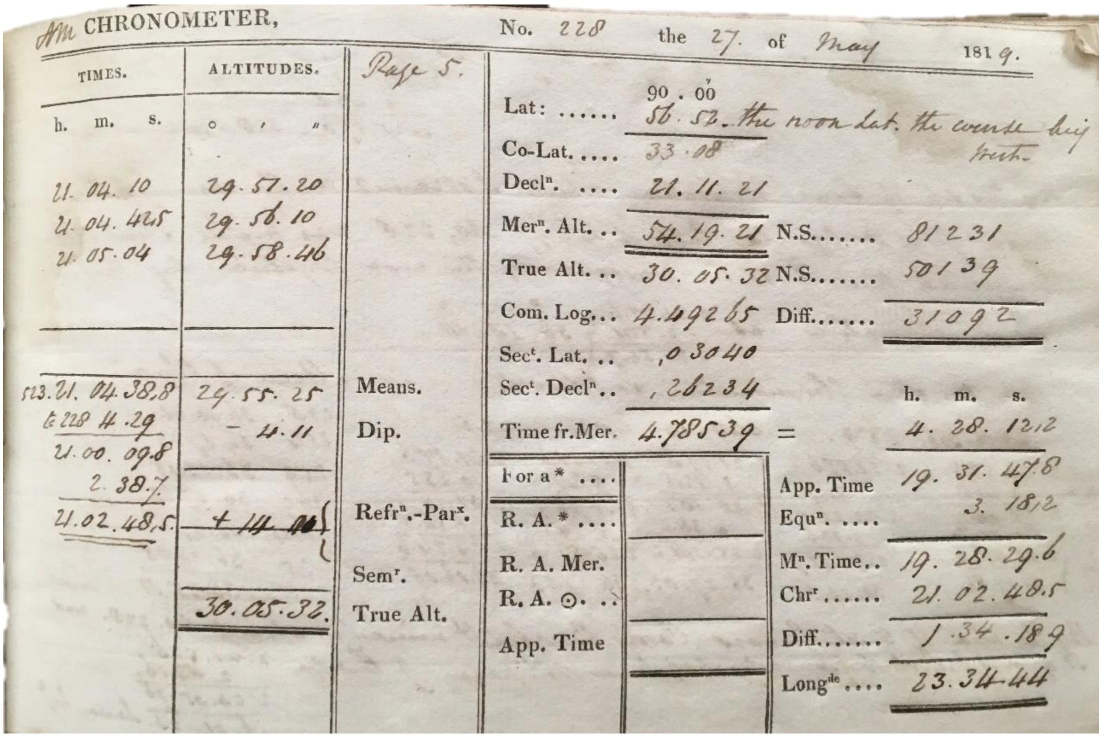


Figure 6.4: Longitude calculation 27 May, 1819. RS, MS/831

This shows the abstract of Sabine's own observations to determine the time and the latitude.

The opposite page contains the abstract from the other observers and chronometers (figure 6.5).

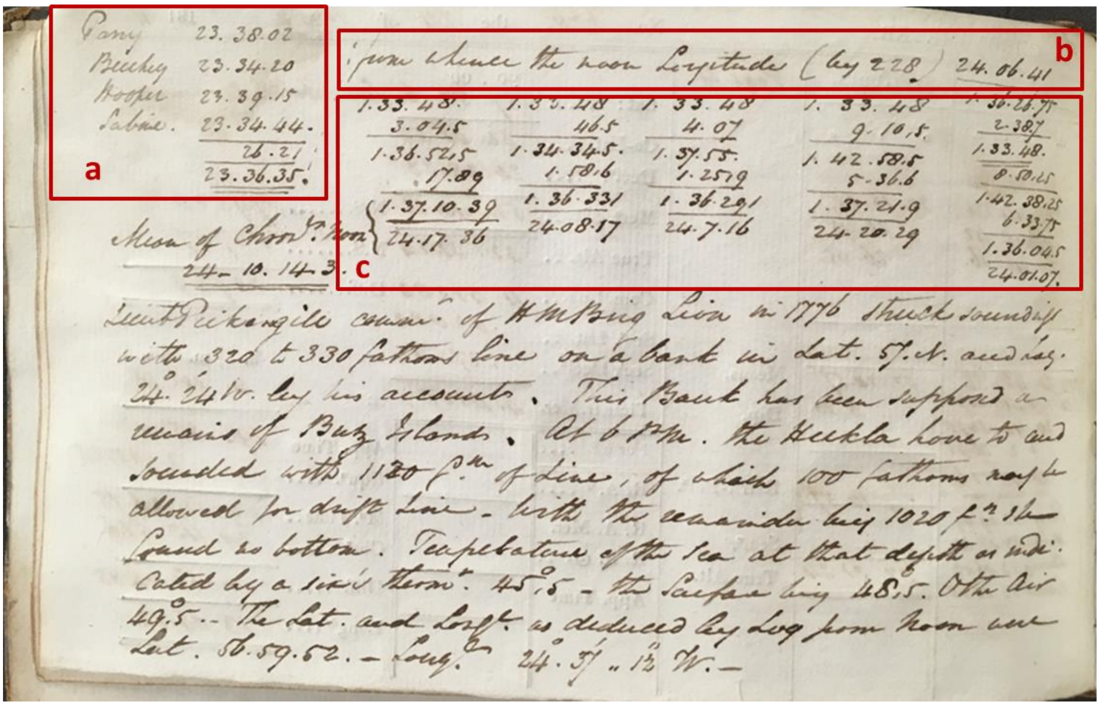


Figure 6.5: Computation of longitude by four observers, 27 May, 1819. RS, MS/831

The calculations for longitude in Sabine's astronomical observation book (figure 6.1) were based solely on the altitudes measured by Sabine on the morning of 27 May. But, at Winter Station, Sabine re-determined the rates and collected the longitudes as established by Parry, Beechey and Hooper (Figure 6.5 section a). Here, we see Sabine's longitude calculation of 23°34'44". Based on the mean of the observations by four observers (and again, adding the distance as determined by dead reckoning), Sabine calculated a new noon longitude by P&F 228 as 24°06'41" (figure 6.5 section b). Based on this, Sabine recalculated the longitude for each chronometer (figure 6.5 section c). From this calculation we also see that Sabine gave equal weight to each observer, indicating that these four were those he trusted most to take the observations.

8. Noon longitude recalculated for each chronometer based on the new rates determined by the lunar distances.

These determinations were copied from Sabine's astronomical observation book. Based on the new rates established at Winter Station, and the new rates as determined by the lunar distances, the longitude for each chronometer was calculated. Unlike with Captain Owen, the distinction between chronometers used on deck and those kept below decks was not clear cut. In this example, pocket chronometer Arnold 523 was used to time the observations for both latitude and longitude. Initially, in the first calculations, it was included in the mean calculation for longitude. Possibly due to the severe cold to which it was subjected during the lunar observations at Winter Harbour, it was not included in the recalculations.

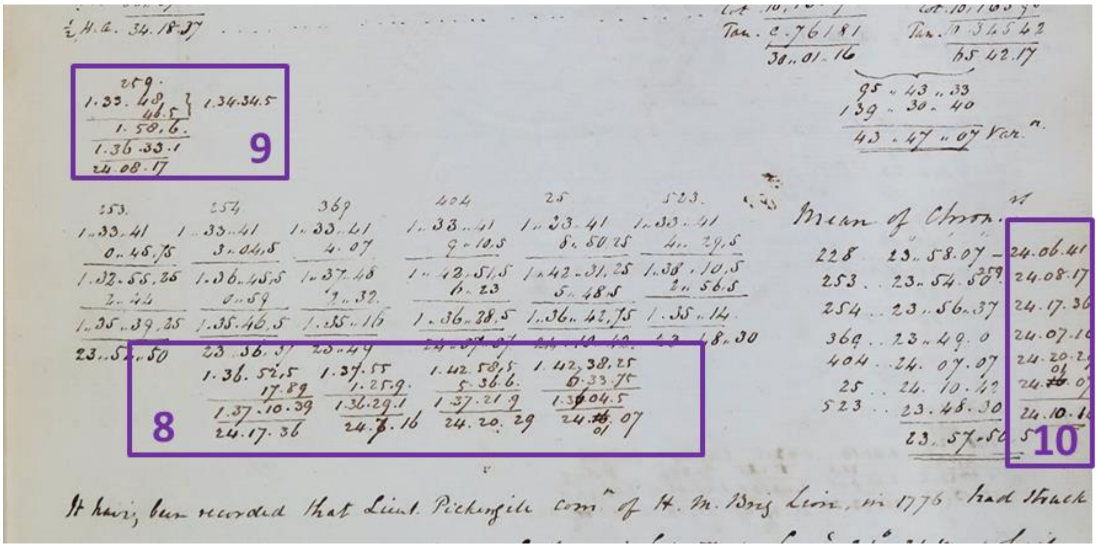


Figure 6.6: Recalculation of the longitude by each chronometer and the mean of all. TNA, BJ3/58

9. Longitude by P&F 259 based on the new rates.

Despite Sabine's warm praise for P&F 253, it is evident that P&F 259 replaced P&F 253 in all the recalculations for longitude that were made at a later date. Based on the stability of its rate at sea and at Winter Harbour, Sabine judged its performance as good enough to include in the calculation.

10. Corrected noon longitude by the mean of six chronometers. Corrected by dead reckoning to noon and by lunars for the rates.

Finally, Sabine determined the noon longitude based on the mean of the longitudes by six chronometers: 228, 259, 254, 369, 404 and 25. This is the noon longitude (24°10'14") as published in the appendix and that found in the 'Abstract of Day's Work'.[29] The results of each individual chronometer can also be found in the appendix in the table 'Longitude by each Chronometer'.[30] The majority of the calculations within this workbook follow the same pattern: the initial calculations taken on voyage were later recalculated with the new rates. In each case, chronometers P&F 253 and Arnold 523 were excluded, and P&F 259 was

[29] Parry, *Journal of a Voyage 1819-1820,* Appendix, p. cxlvii

[30] Ibid, pp. lxxx-lxxxiii

included in the mean. During the 1820 navigation season, numbers 369 and 404 were excluded after they had stopped.

The noon longitude that Sabine calculated based on the mean of the four observers and six chronometers differs from those found in other documents. Beechey's log book records a noon longitude of 22°58'36" which is corrected to 24°05'20" in pencil. This does not match the longitude as noted by Sabine in his chronometer book (see figure 6.5 section a: longitude 23°34'20"). It can therefore be assumed that Beechey also kept a record of his observations and performed his own corrections with the new chronometer rates. Parry's journal also records a different determination; 23°59'50" which was also corrected, to 24°06'39".[31] These do not match those that Sabine recorded, although Sabine's determination in the appendix remained the official version. In the rough version of the Day's Work the longitude is noted as 24°06'39".[32] Each officer kept his own determinations and calculations but Sabine, and only Sabine, collected and organised all the different data into the official output.

In this way, a positional point of latitude and longitude comprised the following: latitude, as taken by a meridian observation; dead reckoning, by keeping track of course and distant; longitude, as determined by altitudes timed by a chronometer; lunar distances, taken whenever possible to assign a correct error and rate to the chronometers. This may be taken further to include three or four observers; sextant(s) with or without an artificial horizon; notebooks and logarithmic tables; log and line; compass; the *Nautical Almanac*; *Tables Requisite* and six chronometers. Positional points of latitude and longitude were constructed using multiple observers, instruments, tables and calculations, and were subject to revision

[31] *Hecla*: Journal with Appendix Kept by W. E. Parry, 4 May 1819 to 26 September 1819. TNA, ADM/55/157-1

[32] HMS *Hecla*, Account of the Construction of the Charts on board the *Hecla*, 1819-1820. UKHO, Survey Data Books, Miscellaneous Books, 25.

and recalculation at a later date. A longitude determination was therefore never ‘on-the-spot’, as it always required considerable recalculation based on the continuous monitoring of the instruments, or, error management.

Keeping the books

On board the *Beagle*, officers recorded the details of this daily comparison in the comparison book. Initially, ten chronometers were compared with the standard ‘A’ and ten chronometers with the standard ‘Z’. As the journey progressed, and chronometers broke down or were assigned to surveying ships, there were fewer instruments to compare. Figure 6.7 shows the comparison in September 1836, when only fifteen chronometers were functioning on board the *Beagle.*

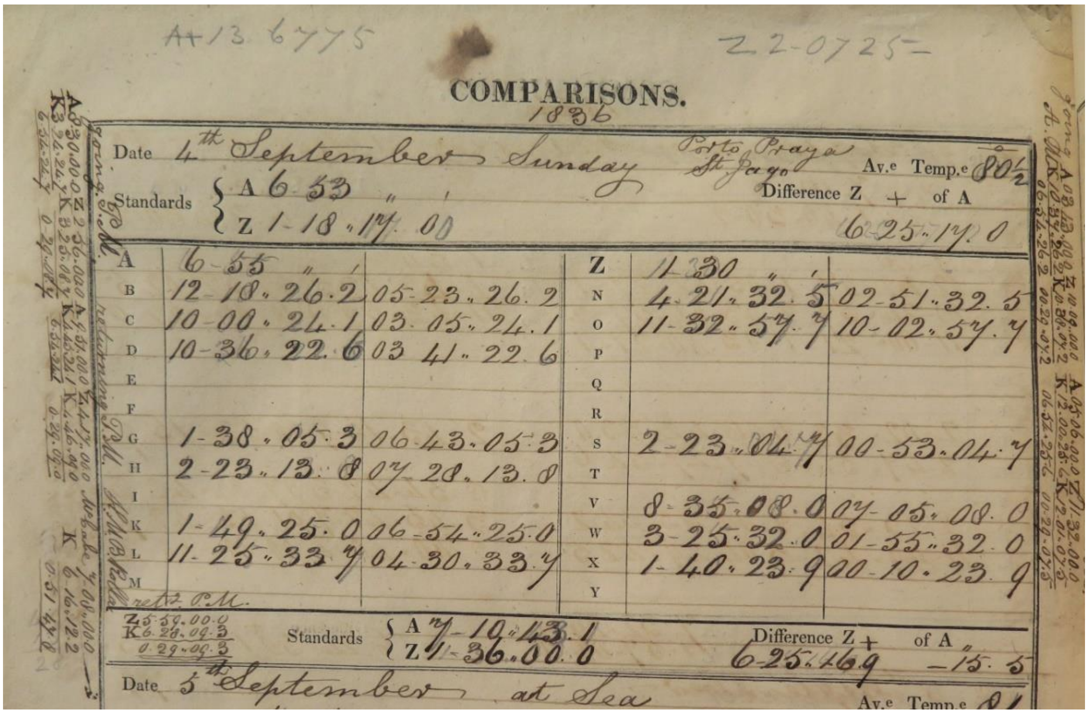


Figure 6.7: Beagle comparison book, 4 September 1836. UKHO, OD807

Examination of the data gives an indication of the process. On 4 September 1836, chronometers A and Z were compared to the others. First the two standards were compared:

A showed 6.53 and B 1.18.17,0. Z was fast of A 6.25.17,0. Two minutes later, at 6.55, A was compared to chronometers B, C, D, G, H, K and L. This process took less than ten minutes. Chronometer Z was subsequently compared to N, O, S, V, W and X at 1.30 (time by Z). The comparison with these six chronometers took less than six minutes as by 1.36 (again according to Z) the two standards were again compared and the daily comparison completed. The times noted in the comparison columns all give the difference between each chronometer and the standard at exactly 6.55. As it would be physically impossible to determine and note the time of seven chronometers with the standard at that instant, this comparison book is clearly the fair comparison book compiled from the notes that would have been made during the comparison. Unfortunately, these do not survive. Assuming, as Shadwell and Owen advised, each chronometer was compared at the whole and at the half minute, this would make it easy for users to recalculate all the comparison back to a single time – subtracting 30 seconds; one minute; one and a half minutes; two minutes etc. from each consecutive comparison. The comparison of these 15 chronometers took Stebbing (and his assistant) 17 minutes to complete, evidence of their skills of comparison.

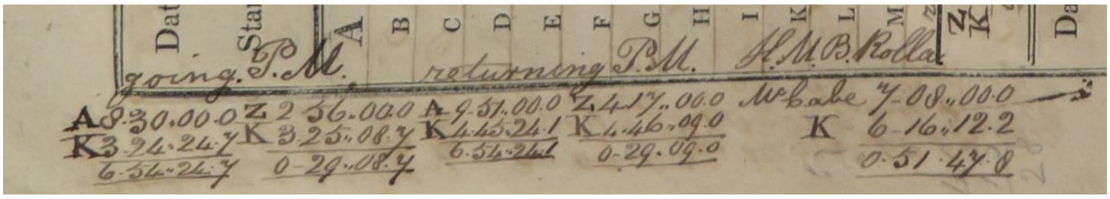


Figure 6.8: Detail of Beagle comparison book – comparison of chronometer K. UKHO, OD807

More comparisons were inserted in the margin, the same day pocket chronometer K (P&F 1042) was compared with the standards A and Z.[33] This particular example is the comparison before and after the morning observations. These were not inserted daily, but only when necessary for obtaining sights for either general navigational purposes or for obtaining the

[33] Interestingly a McCabe chronometer was also compared, being listed as belonging to HMB *Rolla*. This indicates that the *Beagle* provided a comparison service for this vessel.

necessary shore observations for rating the chronometers. By comparing the chronometers' times at 'going PM' (A = 8.30.00.0) and 'returning PM' (A = 9.51.00.0), the time taken for these observations was one hour and twenty-one minutes. Similar comparisons from other pages show that these morning or evening observations could take over two hours.

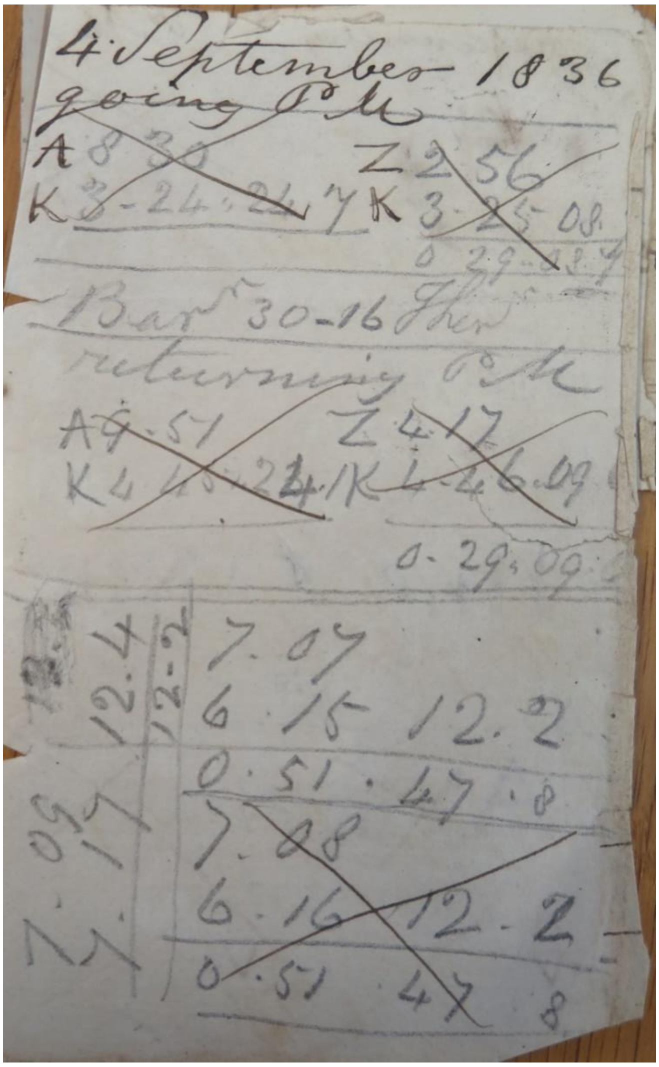


Figure 6.9: Note inserted in the pages of the *Beagle's* Comparison Book. UKHO, OD807.

As can be seen from the above note, the comparison was made in pencil on scraps of paper, before being copied in pencil and later ink in the comparison book. The figures that are crossed out are those that have been copied into the book. We can assume that the practice for the daily comparison was similar. This tiny note can be found folded within the pages of the comparison book.

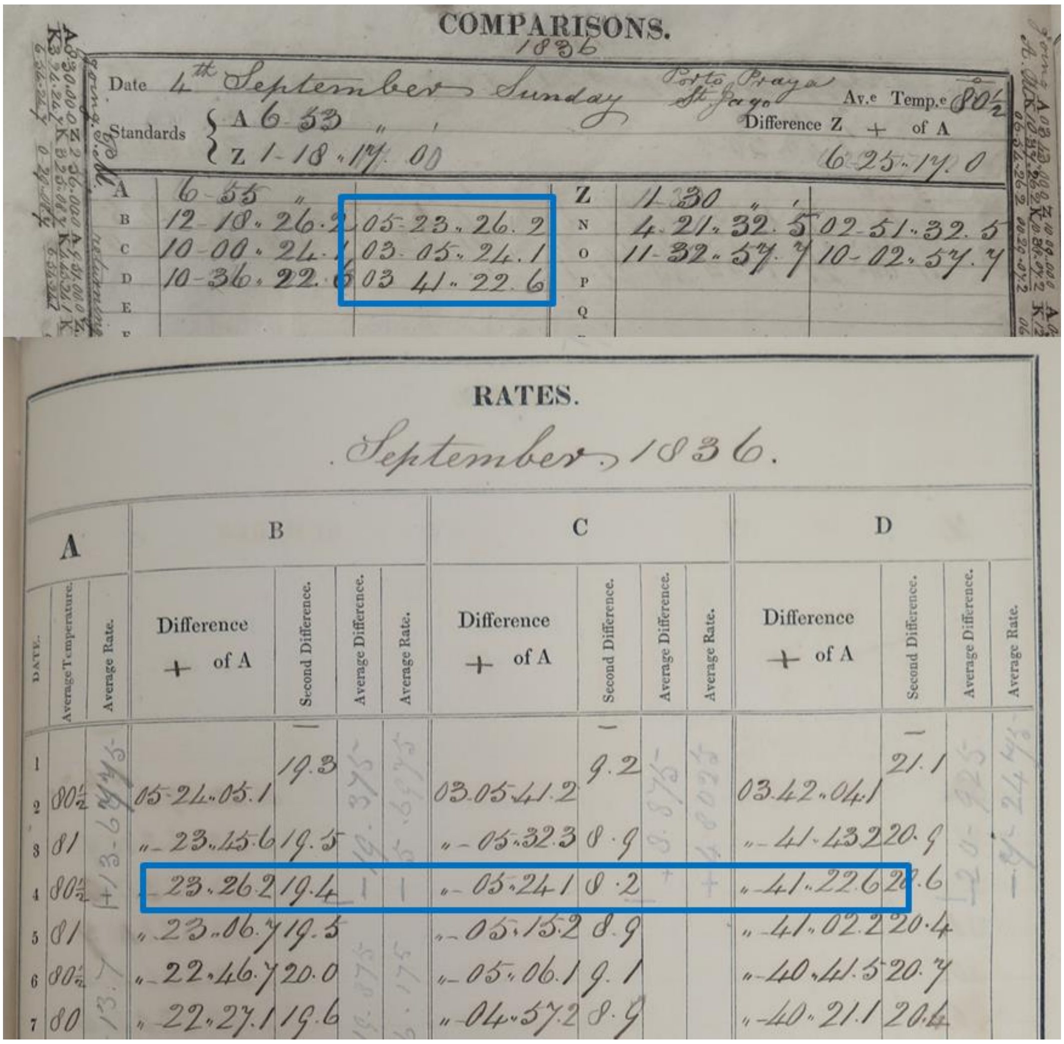


Figure 6.10: Depicting the relationship between the comparison and rate books. HMS *Beagle* September, 1836. UKHO, OD807 and OD821.

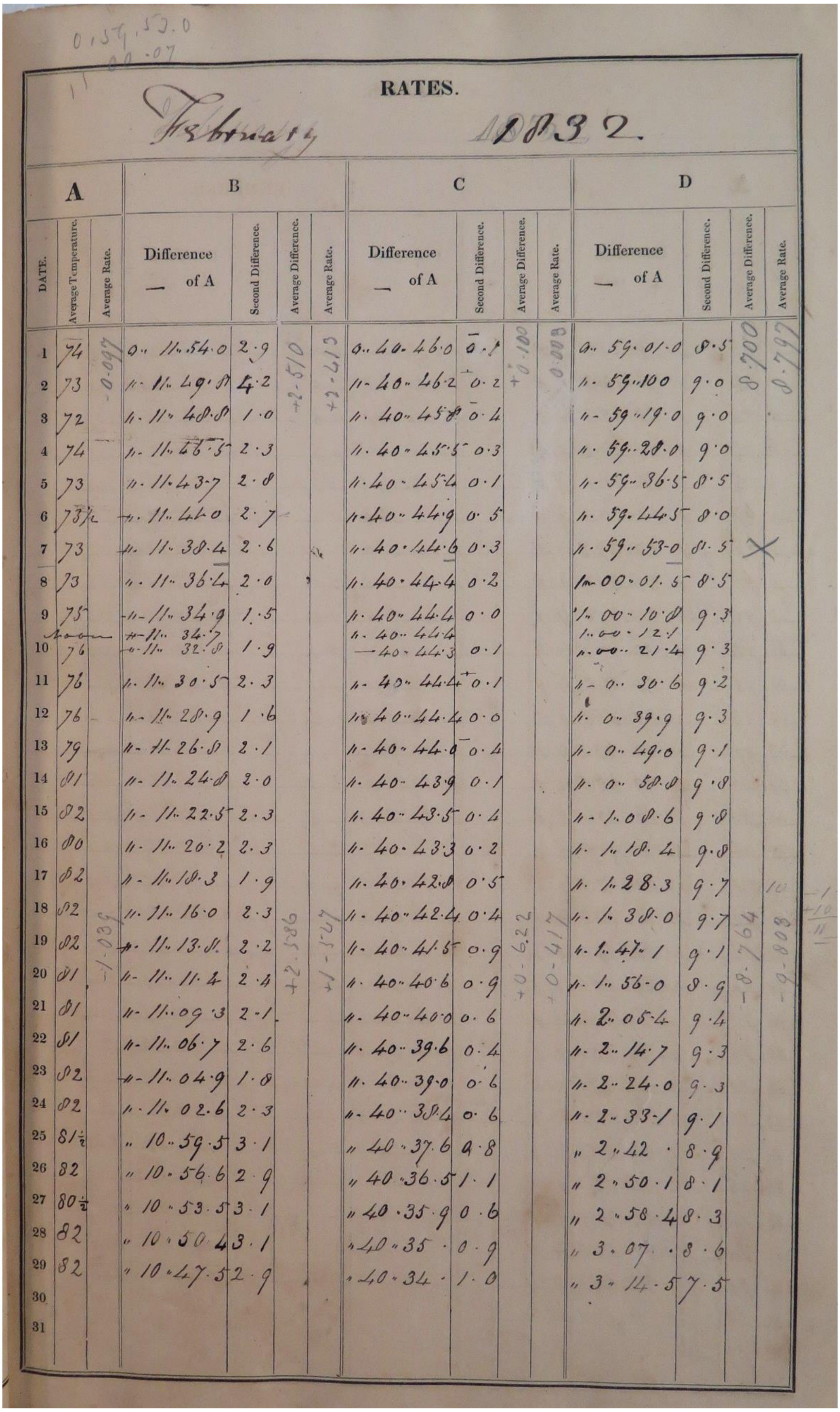
From the daily comparison book, the data was copied into the *Beagle* rate book (figure 6.10). It was from this that users determined which chronometers kept their rates steady or when fluctuations occurred. The chronometer rate book kept on the *Beagle* is a hefty folio volume containing the daily differences between December 1831 and October 1836. Each page contains the monthly comparison of all the chronometers against the standards A or Z. Each month thus contains eight pages.[34] A remarks column was included every four pages where

[34] Page 1: A compared to B, C and D; Page 2: A compared to E, F and G; Page 3: A compared to H, K and L; Page 4: A compared to M; Page 5: Z compared to N, O and P; Page 6: Z compared to R, S and T; Page 7: Z compared to V, W and X; Page 8: Z compared to Y

occasionally interesting details on the instruments were included. A frequent comment added was '(X, Y or Z) increased or decreased its daily difference'.

From the comparison book, the difference between the standard and the chronometer in question was inserted into the column 'difference +/- of A' or 'difference +/- of Z' (figure 6.10). The next column was for the second difference; this was the daily difference between the differences in the previous column, either gaining or losing. The third and fourth columns (for the 'average difference' and the 'average rate') were often left blank. The first column, next to the dates, recorded the temperature. Fluctuations could be compared against variations in temperature. Figure's 6.11 and 6.12 are two pages of the rate books kept on HMS *Beagle.*

Selecting a standard and keeping comparison and rate books enabled users not only to check the regularity of the chronometers at sea, but also to correct or appoint new rates at any given time. Rates for chronometers could only be determined by astronomical observations on shore, provided that the ship remained at that spot for several days. For surveying vessels progressing more slowly whilst remaining close to the coast, this presented fewer problems than for ships navigating two weeks crossing the Atlantic between two ports, especially if the goal was to establish a meridian distance. As we have seen, the accuracy of chronometric measurements diminished the longer the period between two ratings. Additionally, greater geographical distances increased the likelihood of external factors influencing the going of the chronometers (temperature variations, movement, magnetism, etc.). In addition, because the chronometers could not be rated in transit, *when* a rate was affected could not be established. This could be a problem if a ship were to stop at additional places included in the meridian measurements, but where the rate was not established separately. Assigning a rate was not straightforward but relied on the judgements of the officers involved.



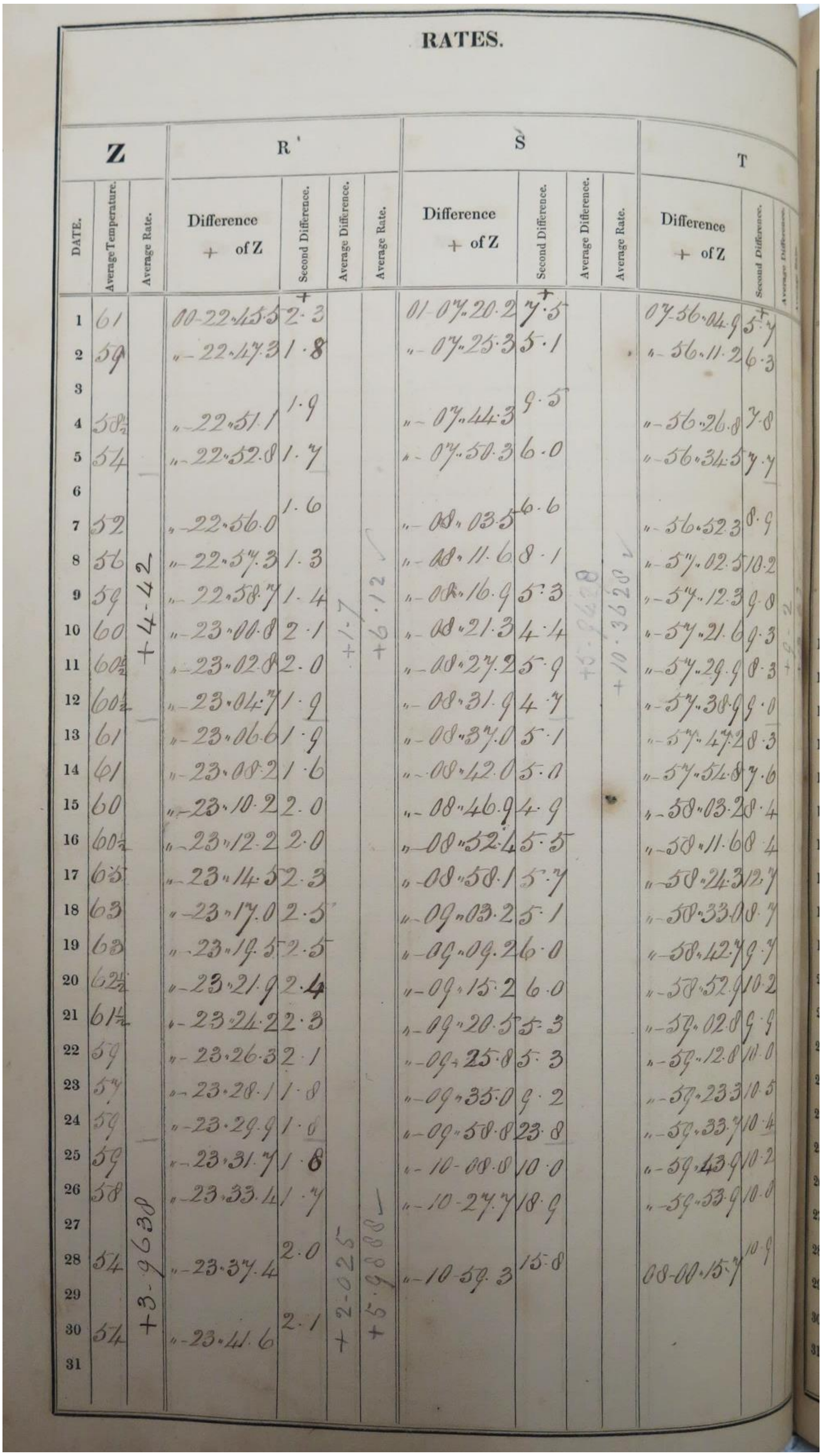
0.59.53.0
00.07

RATES.

February 1832.

	A		B				C				D			
DATE.	Average Temperature.	Average Rate.	Difference — of A	Second Difference.	Average Difference.	Average Rate.	Difference — of A	Second Difference.	Average Difference.	Average Rate.	Difference — of A	Second Difference.	Average Difference.	Average Rate.
1	74	-0.097	0.. 11..54.0	2.9	+2.510	+2.413	0..40..46.0	0.1	+0.100	0.008	0.. 59.01.0	8.5	8.700	8.797
2	73		″ 11..49.8	4.2			″ 40..46.2	0.2			″ 59..100	9.0		
3	72		″ 11..48.8	1.0			″ 40..45.8	0.4			″ 59..19.0	9.0		
4	74		″ 11..46.5	2.3			″ 40..45.5	0.3			″ 59..28.0	9.0		
5	73		″ 11..43.7	2.8			″ 40..45.4	0.1			″ 59..36.5	8.5		
6	73½		″ 11..44.0	2.7			″ 40..44.9	0.5			″ 59..44.5	8.0		
7	73		″ 11..38.4	2.6			″ 40..44.6	0.3			″ 59..53.0	8.5		
8	73		″ 11..36.4	2.0			″ 40..44.4	0.2			1m 00..01.5	8.5		
9	75		″ 11..34.9	1.5			″ 40..44.4	0.0			1..00..10.8	9.3		
Noon			″ 11..34.7				″ 40..44.4				1..00..12.1			
10	76		″ 11..32.8	1.9			— 40..44.3	0.1			1..00..21.4	9.3		
11	76		″ 11..30.5	2.3			″ 40..44.4	0.1			″ 0..30.6	9.2		
12	76		″ 11..28.9	1.6			″ 40..44.4	0.0			″ 0..39.9	9.3		
13	79		″ 11..26.8	2.1			″ 40..44.0	0.4			″ 0..49.0	9.1		
14	81		″ 11..24.8	2.0			″ 40..43.9	0.1			″ 0..58.8	9.8		
15	82		″ 11..22.5	2.3			″ 40..43.5	0.4			″ 1..08.6	9.8		
16	80		″ 11..20.2	2.3			″ 40..43.3	0.2			″ 1..18.4	9.8		
17	82		″ 11..18.3	1.9			″ 40..42.8	0.5			″ 1..28.3	9.7		
18	82		″ 11..16.0	2.3			″ 40..42.4	0.4			″ 1..38.0	9.7		
19	82	-1.039	″ 11..13.8	2.2	+2.586	+1.547	″ 40..41.5	0.9	+0.622	+0.417	″ 1..47..1	9.1	-8.764	-9.803
20	81		″ 11..11.4	2.4			″ 40..40.6	0.9			″ 1..56.0	8.9		
21	81		″ 11..09.3	2.1			″ 40..40.0	0.6			″ 2..05.4	9.4		
22	81		″ 11..06.7	2.6			″ 40..39.6	0.4			″ 2..14.7	9.3		
23	82		″ 11..04.9	1.8			″ 40..39.0	0.6			″ 2..24.0	9.3		
24	82		″ 11..02.6	2.3			″ 40..38.4	0.6			″ 2..33.1	9.1		
25	81½		″ 10..59.5	3.1			″ 40..37.6	0.8			″ 2..42.	8.9		
26	82		″ 10..56.6	2.9			″ 40..36.5	1.1			″ 2..50.1	8.1		
27	80½		″ 10..53.5	3.1			″ 40..35.9	0.6			″ 2..58.4	8.3		
28	82		″ 10..50.4	3.1			″ 40..35.	0.9			″ 3..07.	8.6		
29	82		″ 10..47.5	2.9			″ 40..34.	1.0			″ 3..14.5	7.5		
30														
31														

Figure 6.11: Table of Rates, HMS *Beagle*, February 1832. UKHO, OD821



RATES.

Z			R'				S				T		
DATE.	Average Temperature.	Average Rate.	Difference + of Z	Second Difference.	Average Difference.	Average Rate.	Difference + of Z	Second Difference.	Average Difference.	Average Rate.	Difference + of Z	Second Difference.	Average Difference.
1	61		00-22-45·5	+ 2·3			01-07-20·2	+ 7·5			07-56-04·9	+ 5·7	
2	59		„-22-47·3	1·8			„-07-25·3	5·1			„-56-11·2	6·3	
3				1·9				9·5					
4	58½		„-22-51·1				„-07-44·3				„-56-26·8	7·8	
5	54		„-22-52·8	1·7			„-07-50·3	6·0			„-56-34·5	7·7	
6				1·6				6·6					
7	52		„-22-56·0				„-08-03·5				„-56-52·3	8·9	
8	56		„-22-57·3	1·3			„-08-11·6	8·1			„-57-02·5	10·2	
9	59	+4·42	„-22-58·7	1·4	+1·7	+6·12	„-08-16·9	5·3	+5·8628	+10·3628	„-57-12·3	9·8	+2·2
10	60		„-23-00·8	2·1			„-08-21·3	4·4			„-57-21·6	9·3	
11	60½		„-23-02·8	2·0			„-08-27·2	5·9			„-57-29·9	8·3	
12	60½		„-23-04·7	1·9			„-08-31·9	4·7			„-57-38·9	9·0	
13	61		„-23-06·6	1·9			„-08-37·0	5·1			„-57-47·2	8·3	
14	61		„-23-08·2	1·6			„-08-42·0	5·0			„-57-54·8	7·6	
15	60		„-23-10·2	2·0			„-08-46·9	4·9			„-58-03·2	8·4	
16	60½		„-23-12·2	2·0			„-08-52·4	5·5			„-58-11·6	8·4	
17	65		„-23-14·5	2·3			„-08-58·1	5·7			„-58-24·3	12·7	
18	63		„-23-17·0	2·5			„-09-03·2	5·1			„-58-33·0	8·7	
19	63		„-23-19·5	2·5			„-09-09·2	6·0			„-58-42·7	9·7	
20	62½		„-23-21·9	2·4			„-09-15·2	6·0			„-58-52·9	10·2	
21	61½		„-23-24·2	2·3			„-09-20·5	5·3			„-59-02·8	9·9	
22	59		„-23-26·3	2·1			„-09-25·8	5·3			„-59-12·8	10·0	
23	57		„-23-28·1	1·8			„-09-35·0	9·2			„-59-23·3	10·5	
24	59		„-23-29·9	1·8			„-09-58·8	23·8			„-59-33·7	10·4	
25	59		„-23-31·7	1·8			„-10-08·8	10·0			„-59-43·9	10·2	
26	58		„-23-33·4	1·7			„-10-27·7	18·9			„-59-53·9	10·0	
27				2·0				15·8				10·9	
28	54	+3·9638	„-23-37·4		+2·025	+5·9888	„-10-59·3				08-00-15·7		
29				2·1									
30	54		„-23-41·6										
31													

Figure 6.12: Table of Rates, HMS *Beagle*, July 1834. UKHO, OD821

The Admiralty trusted Fitzroy to make these judgements as he was 'so accustomed to the management of chronometers, that there is no doubt, with proper precautions and with proper formulæ for determining their rates, that he will succeed in obtaining good results in reasonably short intervals of time and in gradual changes of temperature'. Even so, the Admiralty also cautioned Fitzroy that 'after long periods, and sudden changes of heat and cold, it will be absolutely necessary to check them by astronomical means'.[35] In general, Fitzroy settled on the 'method used by Dr. Tiarks' for determining their rates, with a few exceptions when 'that [method] used by Flinders, Owen, Foster, King, and others, was employed'.[36] In his notebook, Stokes wrote about the method for correcting the rates of chronometers between two stations when the rates had altered on voyage. In this, he quoted Richard Owen's 'Essay', which considered that an incorrect 'and very common method' of accounting for the rate (by arithmetical proportion) had been practised by Flinders (and others). After 'reflecting upon the subject', Stokes concluded that Flinders' method was accurate and stated multiple approaches to detect a variation in rate.[37] The correct method was dependent, according to Stokes, on what was considered the cause of the alteration, and this was a matter of judgement by the individual who managed the chronometers. These variations could occur at any point of the voyage and it was up to the user to divide the interval between ratings into periods (Stokes named these periods 'C' and 'D'). A rate would be ascribed to each period. Another method was to designate a standard chronometer, as 'when there are many chronometers together, and some of them are so invariable in their rates, as to become Standards of comparison for the others, which vary; - the periods C and D may be found, for the varying watches, most satisfactorily. When there are no such means;

[35] Robert Fitzroy, *Narrative of the Surveying Voyages of His Majesty's Ships* Adventure *and* Beagle *between the Years 1826 and 1836, Proceedings of the Second Expedition, 1831-36*, (London: Henry Colburn, 1838), p. 36
[36] Fitzroy, *Narrative of the Surveying Voyages… Appendix to Volume II*, p. 330
[37] John Lort Stokes, General Notebook, probably begun circa 1830. NMM, STK26/1

judgement is the only guide, and no rules can fix those periods exactly in this progression'.[38] In other words, employing a large number of instruments would reduce instrumental error, and help determine at which point on the route an actual change in rate had occurred, to facilitate the more accurate recalculation of the results.

Tiarks' method of interpolation to determine the change of rate of a chronometer differed. To avoid applying a rate based on a uniform manner of change, he described his mathematical formula to get a more accurate rate that could be applied to shorter periods between the intervals of rating. His formula was, he considered, 'more correct and rather more simple' than those adopted by Flinders, Owen, King and Foster.[39] Although a table of comparison was helpful, it was also pointed out that if all chronometers were affected in the same way, it would not be possible using these tables of comparison to determine when an alteration in rates taken place. For example, if temperature variation caused an acceleration of rate in all the chronometers, the rate of the standard would increase. When comparing chronometers to the standard, this increase could not be detected because the relation to the standard would remain the same.

Shadwell was still debating these considerations as late as 1861. Without going into unnecessary mathematical detail, I will follow Shadwell's example to point out the broad differences of each approach. One was an arithmetic series, where 'the change of rate increased or decreased uniformly by a given quantity from day to day … adopted by Flinders, King, Owen and others'.[40] The second considered the 'increment or decrement of rate to flow on uniformly by the area of a right-angled triangle, whose base represented the time elapsed,

[38] John Lort Stokes, General Notebook, probably begun circa 1830. NMM, STK26/1

[39] John Lewis Tiarks, 'Dr. Tiarks's Report on Captain Foster's Chronometrical Observations', in: *Narrative of a Voyage to the southern Atlantic Ocean in the Years 1828, 29, 30, Performed in H. M. Sloop* Chanticleer, *Volume II*, W. H. B. Webster, (London: Richard Bentley, 1834), p. 228

[40] Charles F. A. Shadwell, *Notes on the Management of Chronometers and the Measurement of Meridian Distances*, (London; J. D. Potter, 1861), p. 151

and altitude the observed change of rate'.[41] This latter was applied by Fitzroy, Tiarks and Bayfield. In the use of meridian distances, astronomical ability, it seems, was replaced by mathematical functions. Examples of the formulae discussed by Shadwell for assigning correct rates to chronometers go further than those suggested by Tiarks and discussed by Stokes. If a run included multiple measurements of meridian distances (without stopping to determine the rate), Shadwell suggested applying the following:[42]

Then, for the meridian distance from A to K, we have,—

$$\mathbf{M} = \lambda' - \left\{ \lambda + t\left(a + \frac{b}{2}\right) \right\} \qquad (1)$$

from A to B,

$$\mathbf{M}_1 = \lambda_1 - \left\{ \lambda + \left(\tau a + \frac{\tau^2}{2t} \cdot b\right) \right\} \qquad (2)$$

from B to C,

$$\mathbf{M}_2 = \lambda_2 - \left\{ \lambda_1 + \left(\overline{\tau' - \tau}\, a + \frac{\overline{\tau' + \tau} \,.\, \overline{\tau' - \tau}}{2t} \cdot b\right) \right\} \qquad (3)$$

from C to K,

$$\mathbf{M}_3 = \lambda' - \left\{ \lambda_2 + \left(\overline{t - \tau'}\, a + \frac{\overline{t + \tau'} \,.\, \overline{t - t'}}{2t} \cdot b\right) \right\} \qquad (4)$$

If corrections for temperature were also to be taken into account, then the following would apply:[43]

[41] Shadwell, *Notes on the Management of Chronometers,* p. 151
[42] Ibid*,* pp. 157-158
[43] Ibid*,* p. 164

$$M = \lambda' - \left\{\lambda + t\left(a + \frac{b}{2}\right) + t\left(\frac{\theta + \theta'}{2} - \theta_n\right) y\right\} \tag{9}$$

From A to B:

$$M_1 = \lambda_1 - \left\{\lambda + \left(\tau a + \frac{\tau^2}{2t}\, b\right) + \tau\left(\frac{\theta + \theta'}{2} - \theta_1\right) y\right\} \tag{10}$$

From B to C:

$$M_2 = \lambda_2 - \left\{\lambda_1 + \left(\overline{\tau' - \tau}.a + \frac{\overline{\tau' + \tau}.\overline{\tau' - \tau}}{2t}\, b\right) + \overline{\tau' - \tau}\left(\frac{\theta + \theta'}{2} - \theta_2\right) y\right\} \tag{11}$$

From C to K:

$$M_3 = \lambda_3 - \left\{\lambda_2 + \left(\overline{t - \tau'}.a + \frac{\overline{t + \tau'}.\,\overline{t - \tau'}}{2t}\, b\right) + \overline{t - \tau'}\left(\frac{\theta + \theta'}{2} - \theta_3\right) y\right\} \tag{12}$$

The best chronometers were those that did not alter too much in their rates and the rate book helped officers identify those chronometers. Stokes wrote to an unknown recipient, whom he had promised to send 'a short account of the best chronometers'.[44] Although he believed 'others' would be better placed to judge, he considered the three best chronometers on board to be Molyneux 971, Murray 584 and French 4214. He advised his correspondent to look over the rate book in Fitzroy's possession. During the two and a half months stay at Valparaiso in 1834, 'Molyneux and Murray did not alter their rates more than the 1/10 of a second'.[45]

[44] John Lort Stokes, 'Remarks on chronometers and sailing directions'. NMM, STK/31/4
[45] Stokes 'Remarks on chronometers and sailing directions'. NMM, STK/31/4

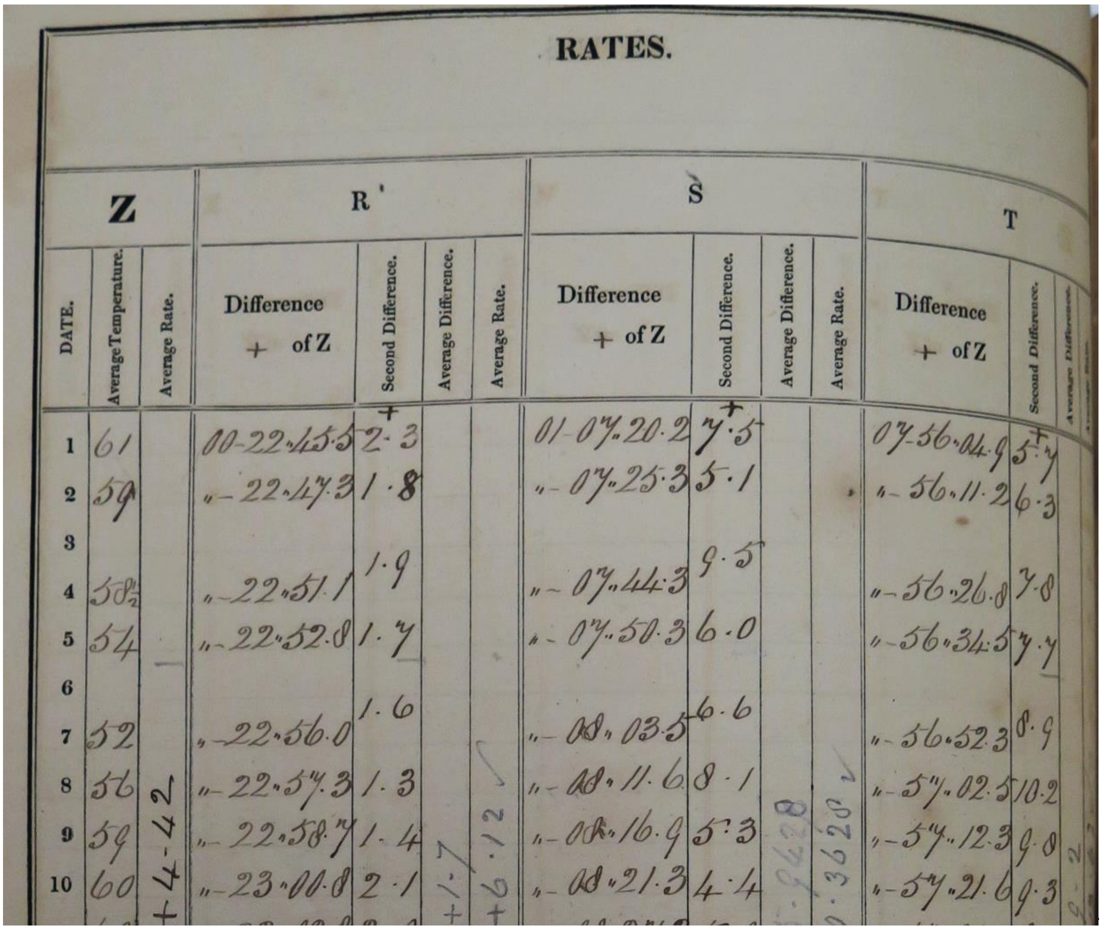


Figure 6.13: Column headings in the *Beagle's* Rate Book. UKHO, OD821

The second difference was meant to indicate whether or not the chronometer varied much in its going (figure 6.13). This was what Stokes referred to in his letter when he suggested an examination of the rate book so the recipient might see for themselves his justification for this. Because this data is hard to read, I have produced a visualisation to make it easier to examine. Figures 6.14 and 6.15 depict in a graph the data taken from the column 'second difference' in the *Beagle's* rate book between December 1828 and February 1829. The chronometers Stokes considered best can be found in figure 6.15. Chronometer 'R' was Murray 584 and chronometer 'N' was Molyneux 971. French 4214 was used as the standard 'Z' and is not represented in the figure.

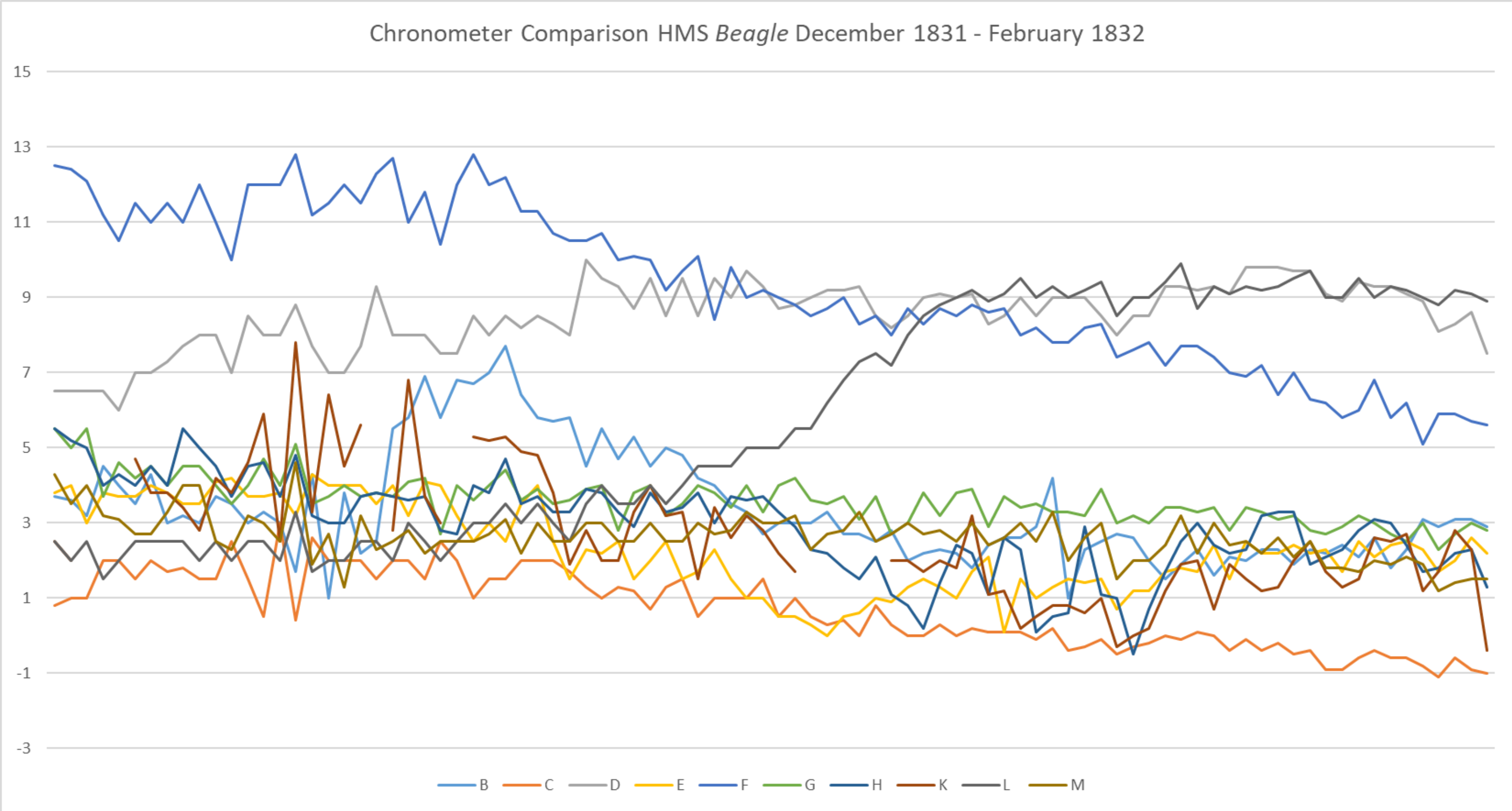


Figure 6.14: Chronometer variations between December 1831 and February 1832 on board HMS *Beagle*, chronometers B – M. UKHO, OD821. The x-axis shows the period of comparison, from December 1831 to February 1832. The y-axis shows the rate of the chronometers in seconds fast or slow of the standard.

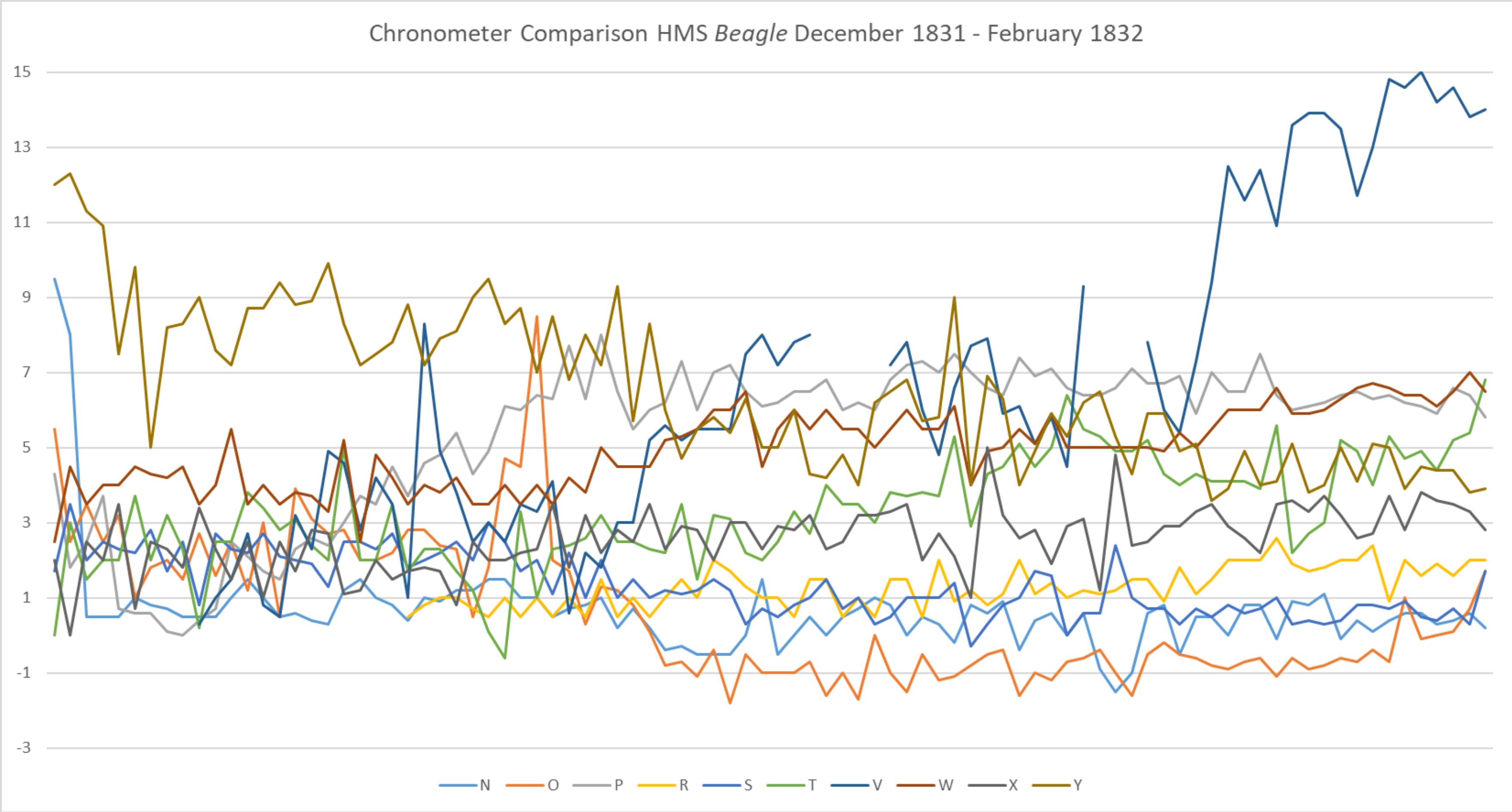


Figure 6.15: Chronometer variations between December 1831 and February 1832 on board HMS *Beagle*, chronometers N – Y. UKHO, OD821.The x-axis shows the period of comparison, from December 1831 to February 1832. The y-axis shows the rate of the chronometers in seconds fast or slow of the standard.

These figures show how easily variations could be detected using these tables of comparisons and rates. The average temperature and barometric pressure were also recorded, but there appears no evidence that this was used to correct for alterations in rate (i.e. by knowing how a certain chronometer responded to temperature alterations and adjusting the rate accordingly), but rather to determine why a chronometer may have altered its rate, and to identify those chronometers that were susceptible to variations in temperature and those that were not.

The only comment concerning the work required to produce these volumes was made by Fitzroy: 'want of room alone prevents my giving the minutest details upon which they depend; it would be of little use to give computations without comparison, or comparisons without rates, or rates without the calculations and observations on which they depend; or any part of these without the whole, which constitutes a mass of figures filling several thick folio books. All these, however, will be deposited at the Hydrographic Office'.[46] What happened to all the 'rough' manuscript material that would have been produced to fill these two hefty volumes of rates and noon comparison is not known. Even the fair comparison book kept between 1831 and 1834 has not survived. This comment underlines how important those observations, calculations, comparisons and rates (or the 'mass of figures') were and makes clear that a substantial amount of time was dedicated to this process.

Early voyages using chronometers for more precise determinations of longitude often relied on the appointment of an astronomer to give credibility to the determinations produced at sea, and the interaction between the chronometer and the astronomical observations was symbiotic and complex. The development of the method of meridian distances relying on chronometric measurements between two or more stations relied on a complex understanding of mathematics and the various ways in which the alteration of rates

[46] Fitzroy, *Appendix to Volume II,* p. 330

could be accounted for. Even then, each singular determination of longitude was dependent on the manner of interpolation or approximation applied. Although astronomers may not have been strictly necessary, advanced astronomical observations on shore were still crucial for the method to succeed. This is examined in more detail in Chapter 7.

Data Management

It was precisely because of the nature of navigation as detailed above that it was important for officers to keep track of all observations and measurements. Foster had produced a mass of data, and Tiarks had been appointed to examine it after the *Chanticleer*'s return. During the voyage, Foster had already been sorting and organising his data, specifically for later examination but also as evidence for his determinations. As is the case for most of the voyages covered in this thesis, not all of the documents that were kept at sea have survived. Despite this, the *Chanticleer*'s documents are the most comprehensive and allow us to understand the importance of managing all the observational data, comparison and rate books, calculations and corrections. Although far from complete, Foster's reports sent during the *Chanticleer*'s voyage to Beaufort reveal how the data collected in the comparison and rate books related to the wider aims of determining meridian distances. A significant part of this came down to observing, noting, collating, examining and managing data.

All observations were taken on land and the results fed back into the chronometer data. The method of meridian distances was the same as that used by Tiarks and was comparatively simple. The chronometers were kept on board ship and not moved from their positions except during winding and the noon comparison. Foster was to sail from station to station: upon arrival and at pre-departure, he was to establish the error and rate of the standard chronometer by Equal Altitudes. As short a run as possible was made between two stations, as the accuracy of the chronometers was believed to decrease over longer intervals.[47] Pre-departure, the error of the chronometer on the Mean Time at the place was determined by either Equal or Absolute Altitudes of the Sun. When the error was determined over consecutive days, a rate was calculated and applied to the next run of the journey. During the run, the daily noon comparison was kept to check the function of each chronometer. Compiled into a table, Foster used this data to select which chronometers he thought reliable to use for the meridian distance. The function of this noon table was two-fold: it allowed Foster to check the function of each chronometer over time, but it also noted the exact difference between each chronometer and the standard at noon each day. Because of this, the noon tables of comparison were one of the most important parts of this practice. Without these, each chronometer would need to be rated separately. From this table the relevant information could easily be extracted. The data could also be readily recalculated if they found the longitude used to establish one meridian distance changed.

We return here to the importance of a hierarchy of instruments. Foster defined three different uses for his chronometers: one chronometer (assuming a pocket chronometer) for timing observations on deck. Another chronometer, one with the steadiest and smallest rate, was employed as a standard, being the one instrument that was compared to the chronometer used during observations and the chronometer against which all the others were compared. All the other chronometers would average out instrumental errors. Chronometers that were used on deck or on shore to time observations were often, but not always, excluded from this average, as this could depend on the performance of the chronometer. The performance was judged by comparing it to the other chronometers through examining the table of daily comparison. Reliability, rather than maker or to which

[47] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956; Jim Bennett, *The Divided Circle: A History of Instruments for Astronomy, Navigation and Surveying*, (Oxford: Phaidon, 1987), p. 179

particular use the chronometer was put to, decided whether a chronometer was considered good enough.

Material held by the Hydrographic Office suggests that Foster kept all his initial observations on loose papers (figures 6.16 and 6.17).[48] Foster then undertook to produce a written-up record of this data in a substantial volume of folio size.[49] Although Foster did occasionally note some rough calculations within this volume, most of it contains the results, rather than the workings. Foster also wrote up reports for each meridian distance. These are kept within the Astronomical Data Books collection held by the Hydrographic Office in Taunton. This collection contains ten folders primarily relating to the meridian distances and contains determinations of latitude of the temporary observatories.[50] Many of these reports are 'written up' versions for a particular station, although some folders contain 'rougher' versions of the same. It becomes clear when viewing these documents that although the method of meridian distances was modelled upon Tiarks' voyage, Foster nevertheless experimented when it came to managing the data. This is most apparent in the tables that Foster constructed based on the information considered important to the process. In his initial drafts, Foster sorted this information into at least seven tables; in others he divided five tables into different parts. He later settled on the latter approach.

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[48] Astronomical Observations, HMS *Chanticleer,* Deception Island, 1829. UKHO, AO32: SFD7/7/1/6
[49] Astronomical Observation Book, HMS *Chanticleer,* 1828-1831. UKHO, SFD9/12/2
[50] HMS *Chanticleer* Astronomical observations. UKHO, OD39 and HMS *Chanticleer* Remarks and observations 1828. UKHO, AO32: SFD7/7/1/1-10.

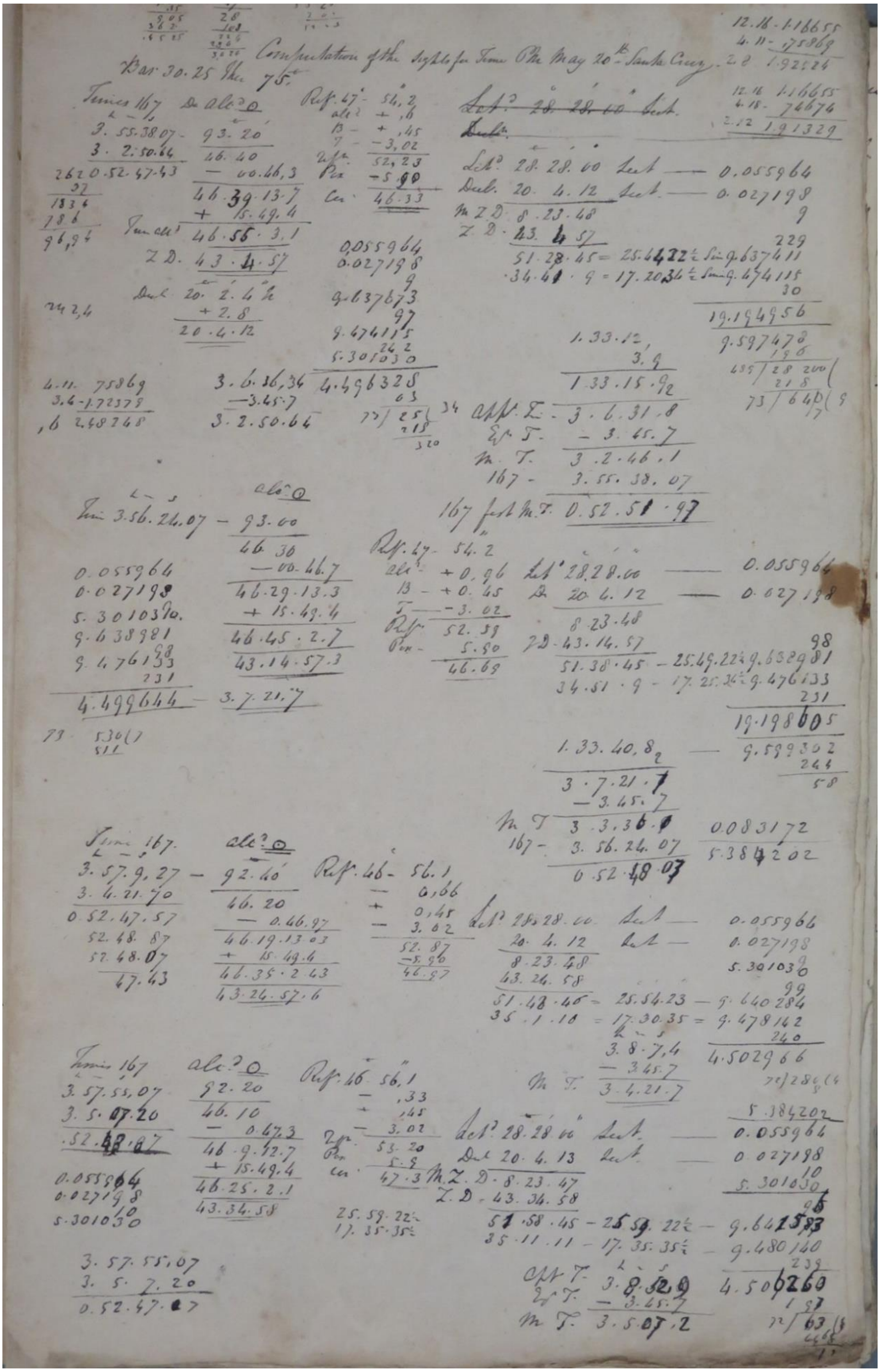


Figure 6.16: Computations of the sights for time PM, 20 May (1831), Santa Cruz. UKHO, AO32: SFD7/7/1/8

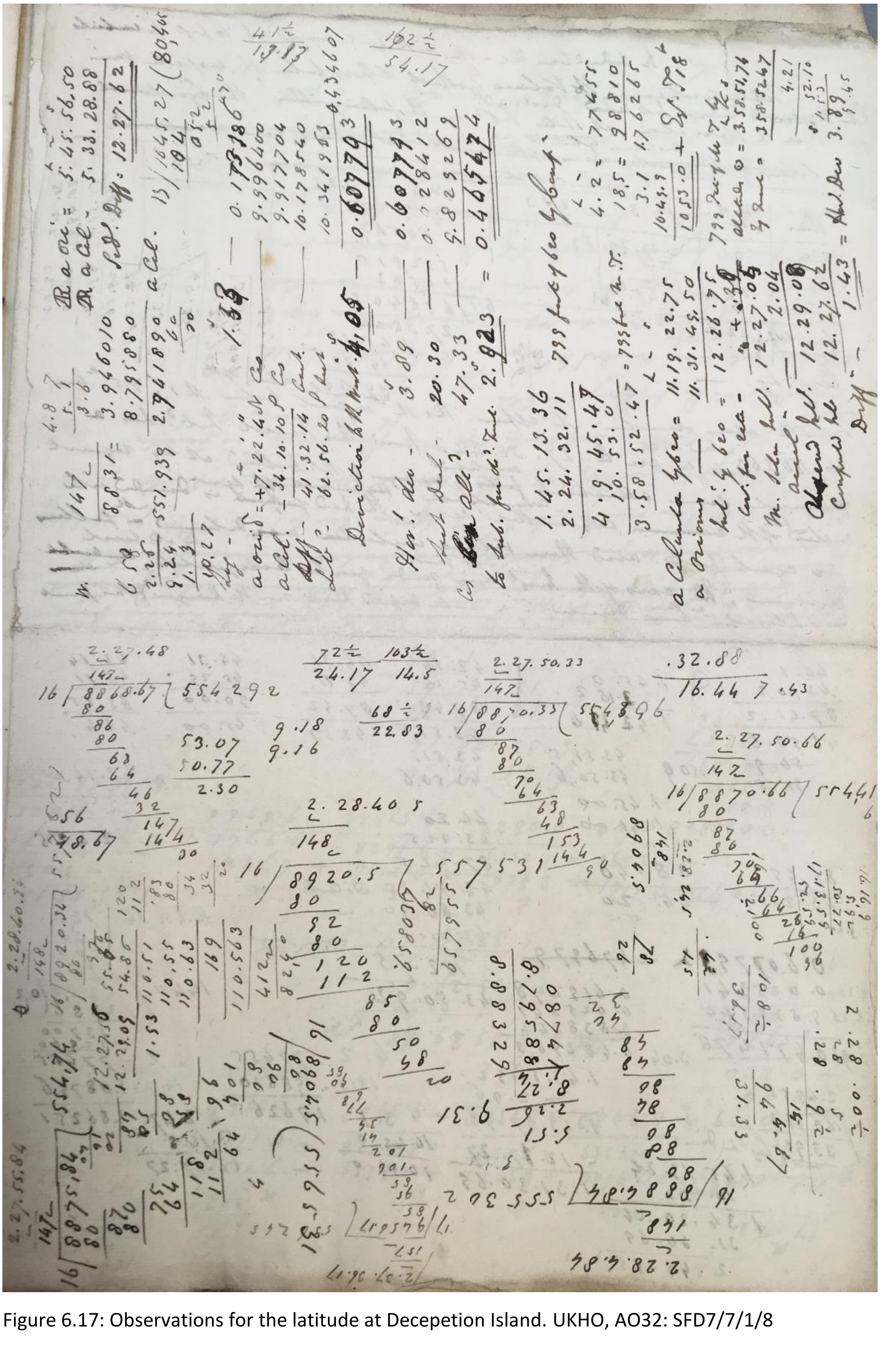


Figure 6.17: Observations for the latitude at Decepetion Island. UKHO, AO32: SFD7/7/1/8

The aim here is not to explain exactly *how* Foster managed his data, but to emphasise the fact that managing data, however done, was crucial to the practice of chronometry. Figure 6.16 shows the computation for local time taken at Santa Cruz. Foster observed altitudes of the Sun timed by McCabe 167 and the subsequent calculation for its error on the Mean Time at Santa Cruz. As McCabe 167 was the standard, it is likely that this document was compiled from another where the timings were made by one of the pocket chronometers (P&F 699 or 799), as these were consistently used for shore observations. Whether or not this is the case, this particular calculation shows the work that is not included in Foster's folio book, nor in the tables constructed from that. Figure 6.17 contains the computations for determining the latitude at Deception Island. It is easy to forget the importance of latitude, but determining the exact latitude for each spot was just as important for establishing the meridian distances between two places.

To keep track of this data, Foster kept a semi-rough book in which he recorded the outcome of the observations made for time and the subsequent determinations for the meridian distance. Although Foster did occasionally note some rough calculations, the majority of this document contains the results, rather than the workings. Based on this document, Foster compiled tables in which he organised what he considered necessary for determining a meridian distance. The meridian distance between Falmouth and Funchal will be taken as an example.

The first rates used on the journey were determined at Pendennis Castle, Falmouth. Foster obtained McCabe 167's error on the Mean Time at Falmouth through twenty-six observations of the sun's lower limb. These results were compared and adjusted using 0°20'10"85 West as the longitude of Pendennis Castle, as determined by Tiarks' meridian distances in 1822, to give the error of McCabe 167 on Mean Time Greenwich at midnight on 1 May. Using the table of comparison, Foster obtained the error for each chronometer. The rate assigned to each chronometer was the difference between the error at Greenwich and the error at Falmouth divided by the number of days elapsed between the two stations. Comparing the error on Mean Time Greenwich determined in March with that determined on 1 May gave the difference during an interval of 36.5 days and subsequently a daily rate for that period. Foster used these rates to establish the meridian distance between Falmouth and Funchal.

On arriving at Funchal, Foster took Equal Altitudes on 12, 14 and 17 May 1828 to determine new rates. He took those in the Consul's garden at Funchal, in exactly the same spot as Tiarks had done six years earlier, to allow direct comparison between their two results. Foster made three calculations for the meridian distance between Falmouth and Madeira: the first using the rates determined at Falmouth, the second using the rates determined at Madeira, and the third using the mean of the two rates. By comparing the results of these three computations, Foster noted that 'the results of the chronometers 699, 799, 620 and 838 differ very considerably from each other, as well as from the mean result of all the rest'. P&F 699 and 799 were used to time the observations on shore in England and Madeira, which may have 'deranged' their rates, and, using the noon comparison table, Foster determined that the change in rates for the other two had occurred during the voyage between England and Madeira. The meridian distance was thus calculated without these chronometers. Between each run, this same method was applied.

The data thus selected and recorded for this meridian distance between Falmouth and Funchal in Foster's folio book contained the following:

- An overview of the errors of the chronometers at Falmouth on, 1 May and a list of the chronometers delivered to the Royal Observatory in preparation for the voyage.
- Observations of the Sun's altitude to determine the time at Falmouth using 699 to time the observations and McCabe 167 as the standard chronometer.
- Observations of the Sun's altitude to determine the time at Funchal 12 May using 799 to time the observations and McCabe 167 as the standard chronometer.
- Calculations to determine the correction for the Equation of Equal Altitudes.
- Computations of the errors of the chronometers at Greenwich and Falmouth, by comparison to the standard McCabe 167.
- Determination of the meridian distance between Falmouth and Funchal using the rates determined at Falmouth.
- Abstract of the above.
- Determination of the meridian distance between Falmouth and Funchal using the mean of the rates determined in England and Madeira.
- Abstract of the above. Additional computations for a meridian distance whereby chronometers 699, 799 and 838 were rejected from the mean and another computation whereby 838, 799, 699 and 620 were rejected from the mean. Included is an overview of similar determinations by other users.
- Determination of the meridian distance between Falmouth and Funchal using the rates determined at Madeira.
- Abstract of the above and the determination of the meridian distance using an average of the rates determined at Falmouth and Madeira.
- Comparison between the standard McCabe 167 and P&F 799 previous and subsequent to the observations on the 12 of May. Comparison between the standard McCabe 167 and all the other chronometers.
- Observations of the Sun's altitude to determine the time at Funchal May 12, 14 and 17 using P&F 799 to time the observations and McCabe 167 as the standard chronometer.
- Errors of the chronometers on Mean Time at Madeira based on the observations made on the 12, 14 and 17 May (Table IV).
- Above continued and a table showing the daily rates of the chronometers on Mean Time by the observations taken at Funchal.

Foster created an abstract of the above which, whenever he had the chance, he sent to Beaufort. Each abstract contains the same documents, based on the observation book described above, and together they give an overview of the steps taken. The following pages contain images of each table and an explanation of their use (figures 6.26 – 6.38). They can be summarised as follows:

1. A list of chronometers and their error on the Mean Time at the place and the rates that were established.
2. The daily noon comparison of each chronometer against the standard.
3. Observations of Equal Altitudes taken to determine the error of the local Mean Time at the next station.
4. New rates determined at the next station based on the observations taken there, calculated for each chronometer using the daily comparison.
5. The meridian distance between the two stations, computed using the old rates, new rates and the mean of the rates.

A brief description of these tables follows. Table 1 contained a list of the chronometers supplied to the *Chanticleer* (figure 6.18). There are only two examples of these tables; this one, drawn up by Foster on departure and a second, drawn up by Lieutenant Austin, acting commander of the voyage following Foster's death.

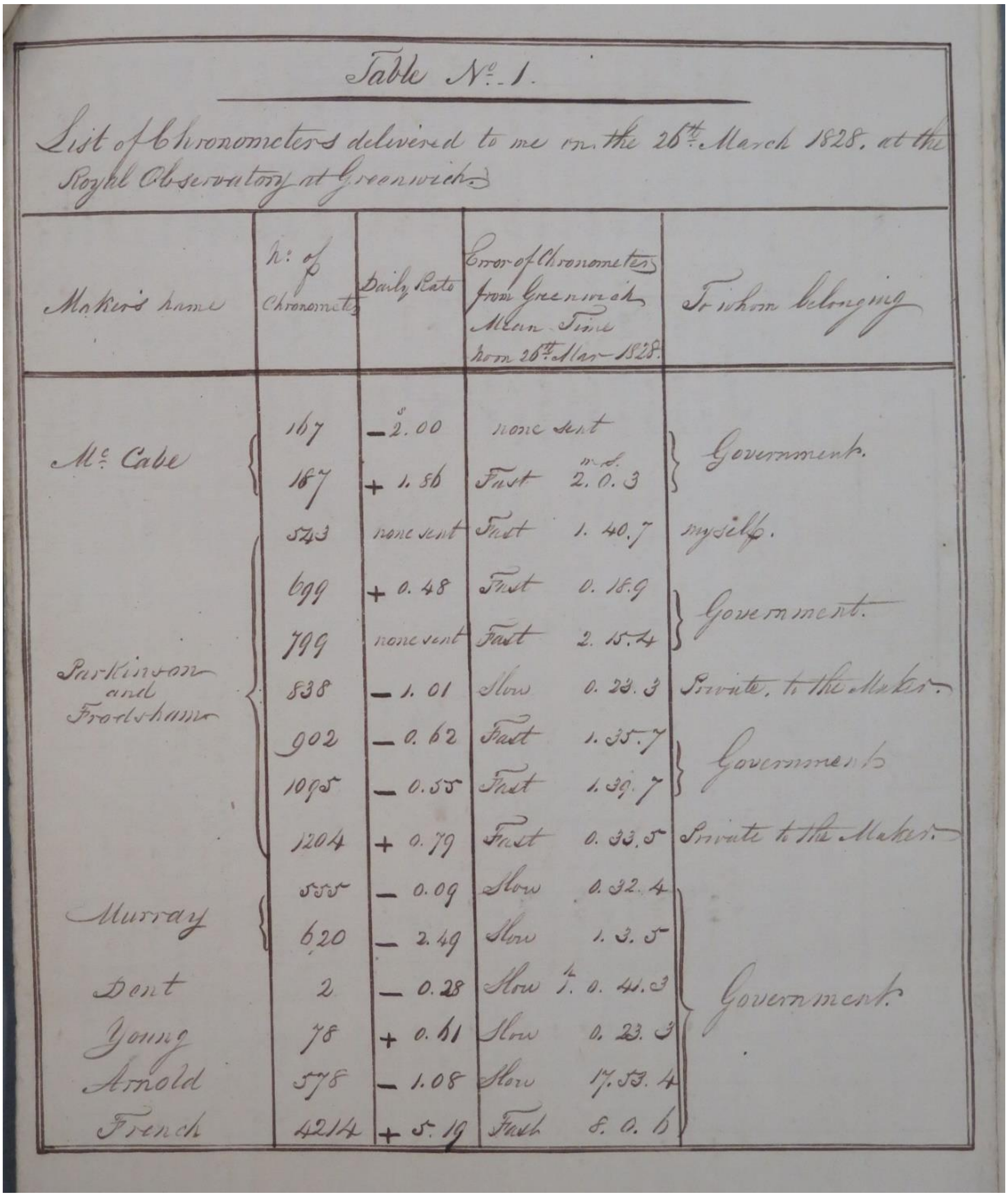


Table No. 1.

List of Chronometers delivered to me on the 26th March 1828, at the Royal Observatory at Greenwich.

Maker's name	No. of Chronometer	Daily Rate	Error of Chronometers from Greenwich Mean Time noon 26th Mar 1828	To whom belonging
McCabe	167	− 2.00	none sent	Government.
	187	+ 1.56	Fast 2.0.3	Government.
	543	none sent	Fast 1.40.7	myself.
Parkinson and Frodsham	699	+ 0.48	Fast 0.18.9	Government.
	799	none sent	Fast 2.15.4	Government.
	838	− 1.01	Slow 0.23.3	Private, to the Maker.
	902	− 0.62	Fast 1.35.7	Government
	1095	− 0.55	Fast 1.39.7	Government
	1204	+ 0.79	Fast 0.33.5	Private to the Maker.
Murray	555	− 0.09	Slow 0.32.4	Government.
	620	− 2.49	Slow 1.3.5	Government.
Dent	2	− 0.28	Slow 1.0.41.3	Government.
Young	78	+ 0.61	Slow 0.23.3	Government.
Arnold	578	− 1.08	Slow 17.53.4	Government.
French	4214	+ 5.19	Fast 8.0.6	Government.

Figure 6.18: List of chronometers delivered to HMS *Chanticleer* in March 1828. UKHO, AO32: SFD7/7/1/7

Table 2 was kept consistently during the voyage and contained the daily noon comparison of each chronometer against the standard (figure 6.19). The documents from which this table was constructed do not survive, but there would have been a manuscript noting the daily difference on which this was based.

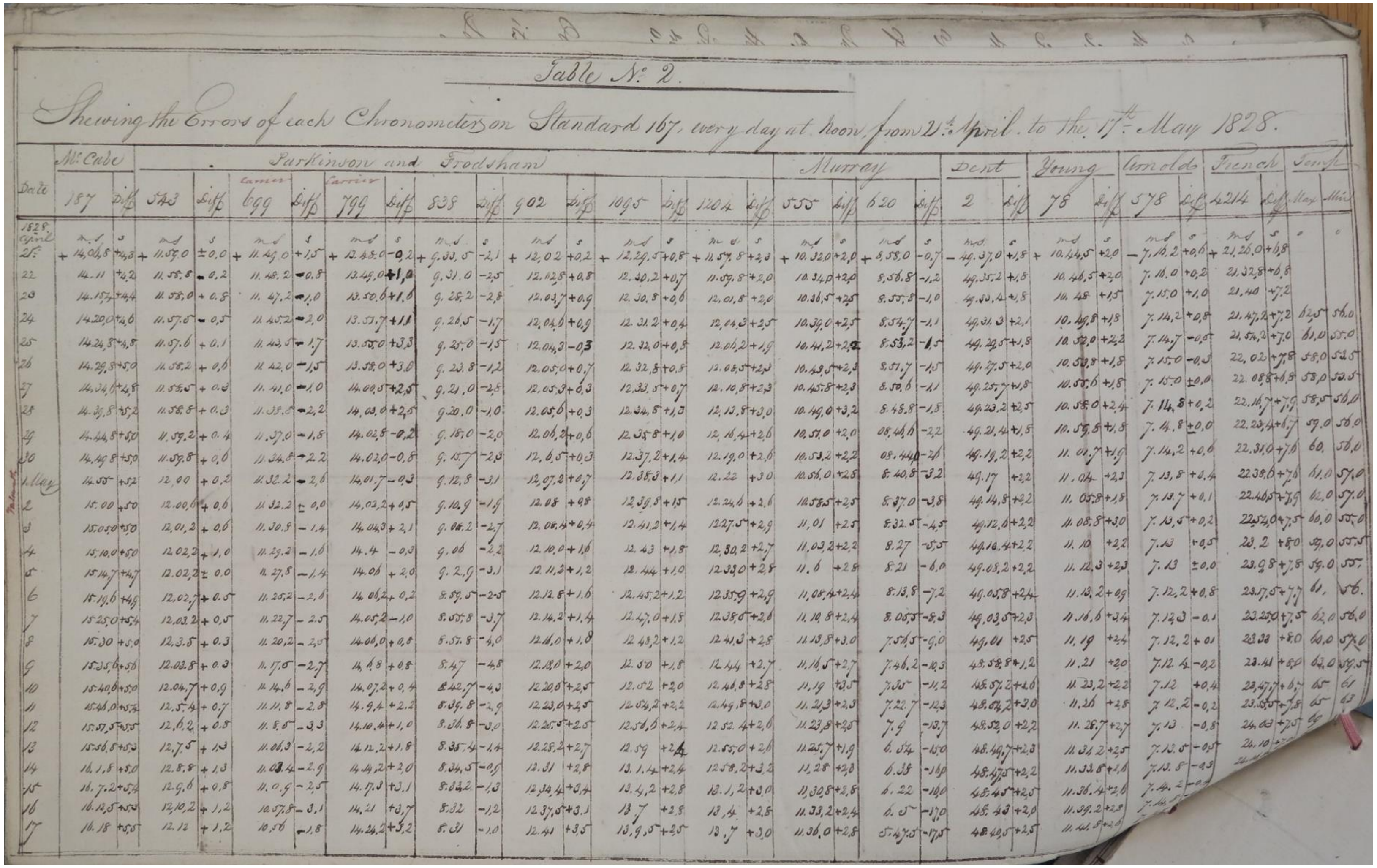


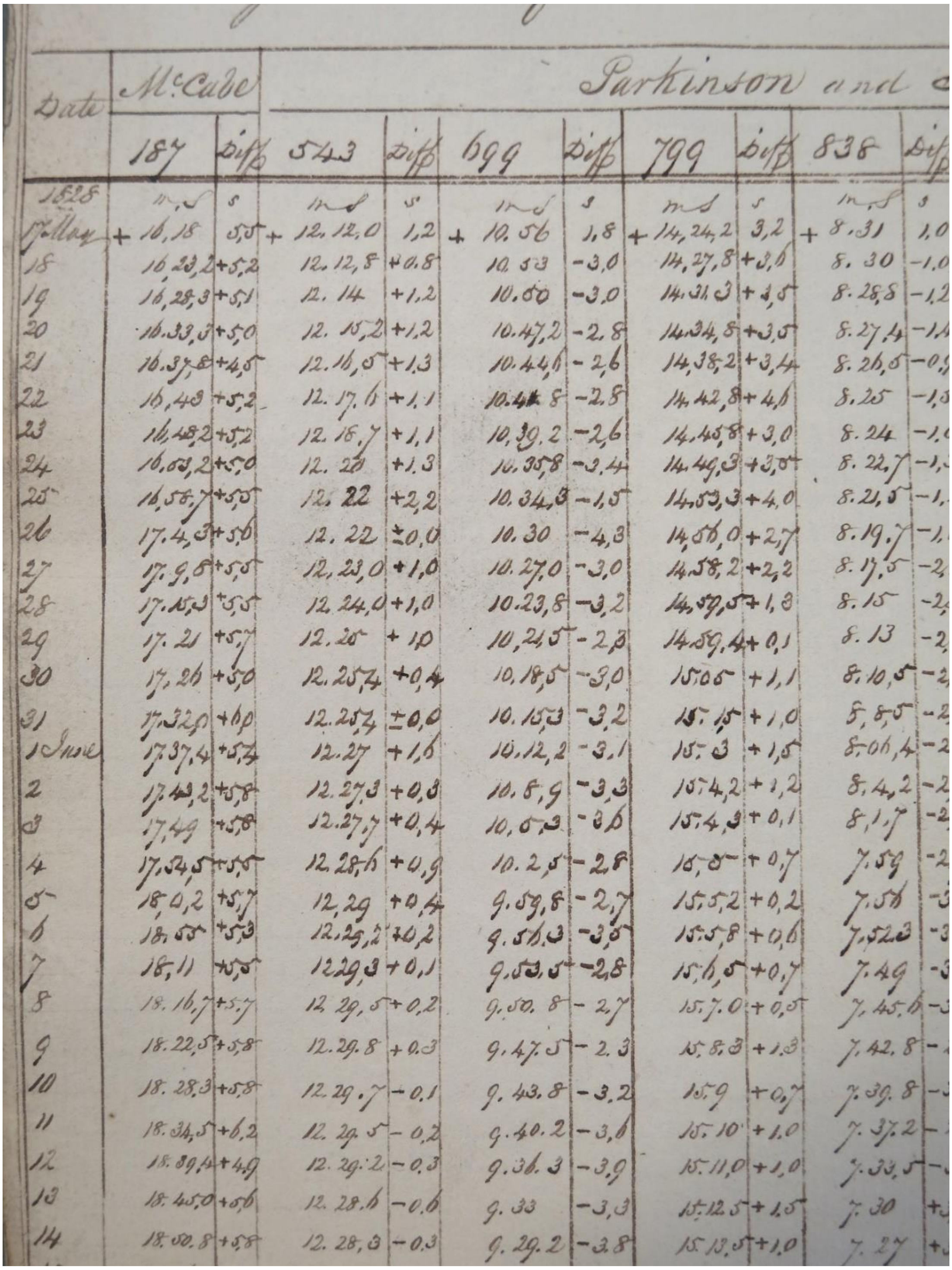
Table N. 2.

Shewing the Errors of each Chronometers on Standard 167, every day at noon, from 21st April to the 17th May 1828.

Date	McCabe		Parkinson and Frodsham														Murray				Dent		Young		Arnold		French		Temp	
	187	Diff	543	Diff	699 (Carrier)	Diff	799 (Carrier)	Diff	838	Diff	902	Diff	1095	Diff	1204	Diff	555	Diff	620	Diff	2	Diff	78	Diff	578	Diff	4214	Diff	Max	Min
1828. April	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	m s	s	°	°
21st	+ 14.04,8	+4,8	+ 11.57.0	±0.0	+ 11.49.0	+1,5	+ 13.48.0	-0,2	+ 9.33,5	-2,1	+ 12,02	+0,2	+ 12.29,5	+0,8	+ 11.57,8	+2,3	+ 10.32,0	+2,0	+ 8,58,0	-0,7	− 49.37,0	+1,8	+ 10.44,5	+2,0	− 7.16.2	+0,6	+ 21.26.0	+6,8		
22	14.11	+4,2	11.58.8	-0.2	11.48.2	-0.8	13.49,0	+1,0	9.31.0	-2,5	12.02,8	+0.8	12.30.2	+0,7	11.59.8	+2,0	10.34,0	+2,0	8,56.8	-1,2	49.35,2	+1,8	10.46,5	+2,0	7.16.0	+0,2	21.32,8	+6,8		
23	14.15,7	+4,4	11.58,0	+0.8	11.47.2	-1,0	13.50.6	+1,6	9.28,2	-2,8	12.03,7	+0.9	12.30.8	+0,6	12.01,8	+2,0	10.36,5	+2,5	8.55,8	-1,0	49.33.4	+1,8	10.48	+1,5	7.15.0	+1,0	21.40	+7,2		
24	14.20,0	+4,6	11.57.5	-0,5	11.45.2	-2,0	13.51,7	+1,1	9.26.5	-1,7	12.04,6	+0,9	12.31.2	+0,4	12.04,3	+2,5	10.39,0	+2,5	8.54,7	-1,1	49.31.3	+2,1	10.49,8	+1,8	7.14,2	+0,8	21.47,2	+7,2	62,5	56.0
25	14.24,8	+4,8	11.57.6	+0.1	11.43,5	-1,7	13.55,0	+3,3	9.25.0	-1,5	12.04,3	-0,3	12.32.0	+0,8	12.06,2	+1,9	10.41,2	+2,2	8.53,2	-1,5	49.29,5	+1,8	10.52,0	+2,2	7.14,7	-0,5	21.54,2	+7,0	61,0	55.0
26	14.29,8	+5,0	11.58,2	+0,6	11.42,0	-1,5	13.58.0	+3.0	9.23.8	-1,2	12.05,0	+0,7	12.32,8	+0,8	12.08,5	+2,3	10.43,5	+2,3	8.51,7	-1,5	49.27.5	+2,0	10.53,8	+1,8	7.15.0	-0,3	22.02	+7,8	58,0	52.5
27	14.34,6	+4,8	11.58.5	+0.3	11.41,0	-1,0	14.00,5	+2,5	9.21,0	-2,8	12.05,3	+0,3	12.33.5	+0,7	12.10,8	+2,3	10.45.8	+2,3	8.50,6	-1,1	49.25,7	+1,8	10.55,6	+1,8	7.15.0	±0,0	22.08,8	+6,8	58,0	53.5
28	14.39,8	+5,2	11.58.8	+0.3	11.38.8	-2,2	14.03,0	+2,5	9.20.0	-1,0	12.05,6	+0,3	12.34,8	+1,3	12.13,8	+3,0	10.49,0	+3,2	8.48.8	-1,8	49.23,2	+2,5	10.58.0	+2,4	7.14,8	+0,2	22.16,7	+7,9	58,5	56,0
29	14.44,8	+5,0	11.59.2	+0.4	11.37.0	-1,8	14.02,8	-0,2	9.18,0	-2,0	12.06,2	+0,6	12.35.8	+1,0	12.16,4	+2,6	10,57.0	+2,0	08,46,6	-2,2	49.21,4	+1,8	10.59,8	+1,8	7.14.8	±0,0	22.23,4	+6,7	59.0	56.0
30	14.49.8	+5,0	11.59.8	+0,6	11.34.8	-2.2	14.02,0	-0,8	9.15.7	-2,8	12.6,5	+0,3	12.37,2	+1.4	12.19,0	+2,6	10.53,2	+2,2	08.44,0	-2,6	49.19,2	+2,2	11.01,7	+1,9	7.14,2	+0,6	22.31,0	+7,6	60,	56,0
1 May	14.55	+5,2	12,00	+0,2	11.32.2	-2,6	14,01,7	-0,3	9.12,8	-3,1	12,07,2	+0,7	12.38,3	+1,1	12.22	+3,0	10.56,0	+2,8	8.40,8	-3,2	49.17	+2,2	11.04	+2,3	7.13,8	+0.4	22.38,6	+7,6	61,0	57,0
2	15.00	+5,0	12.00,6	+0,6	11.32.2	±0,0	14,02,2	+0,5	9.10.9	-1,9	12.08	+0,8	12.39.8	+1,5	12.24,6	+2,6	10.58,5	+2,5	8.37.0	-3,8	49.14,8	+2,2	11.05,8	+1,8	7.13.7	+0,1	22.46,5	+7,9	62,0	57.0
3	15.05,0	+5,0	12,01,2	+0,6	11.30.8	-1.4	14.04,3	+2,1	9.06.2	-2,7	12.06.4	+0,4	12.41,2	+1,4	12.27.5	+2,9	11,01	+2.5	8.32.5	-4,5	49.12,6	+2,2	11.08.8	+3,0	7.13,5	+0,2	22.54,0	+7,5	60,0	55,0
4	15,10,0	+5,0	12.02,2	+1,0	11.29.2	-1.6	14.4	-0,3	9.06	-2,2	12.10,0	+1,6	12.43	+1,8	12,30,2	+2,7	11,03,2	+2,2	8.27	-5,5	49.10.4	+2,2	11.10	+2,2	7.13	+0,5	23.2	+8,0	59,0	55,5
5	15.14,7	+4,7	12.02,2	±0.0	11.27,8	-1,4	14.06	+2,0	9.2,9	-3.1	12.11,2	+1,2	12.44	+1,0	12.33,0	+2,8	11.6	+2,8	8.21	-6,0	49.08,2	+2,2	11.12,3	+2,3	7.13	±0.0	23.9,8	+7,8	59.0	55.
6	15.19,6	+4,9	12,02,7	+0.5	11.25,2	-2,6	14.06,2	+0,2	8.59.5	-2.5	12.12.8	+1.6	12.45,2	+1.2	12.35,9	+2,9	11,08,4	+2,4	8.13,8	-7,2	49.05,8	+2,4	11.13,2	+0,9	7.12,2	+0.8	23.17,5	+7,7	61,	56.
7	15.25,0	+5,4	12.03.2	+0,5	11.22,7	-2.5	14.05,2	-1,0	8.55,8	-3.7	12.14,2	+1,4	12.47,0	+1,8	12.38,6	+2,6	11.10,8	+2,4	8.05,5	-8,3	49.03,5	+2,3	11.16,6	+3,4	7.12,3	-0.1	23.25,0	+7,5	62,0	56,0
8	15.30	+5,0	12.3.5	+0.3	11.20,2	-2,5	14.06,0	+0,8	8.57.8	-4,0	12.16,0	+1,8	12.48,2	+1,2	12.41,3	+2,8	11.13,8	+3.0	7.54,5	-9.0	49.01	+2,5	11.19	+2,4	7.12,2	+01	23.33	+8,0	60,0	57,0
9	15.35,6	+5,6	12.03.8	+0.3	11.17,5	-2,7	14.6.8	+0.8	8.47	-4.8	12.18,0	+2,0	12.50	+1,8	12.44	+2.7	11.16,5	+2,7	7.46,2	-10,3	48.58,8	+1,2	11.21	+2,0	7.12.4	-0,2	23.41	+8,0	63,0	59.5
10	15.40,6	+5,0	12.04,7	+0,9	11.14,6	-2,9	14.07,2	+0,4	8.42,7	-4,3	12.20,5	+2,5	12.52	+2,0	12.46,8	+2,8	11,19	+3,5	7.35	-11,2	48.57,2	+2,6	11.23,2	+2,2	7.12	+0,4	23,47,7	+6,7	65	61
11	15.46,0	+5,4	12.5.4	+0,7	11.11,8	-2.8	14.9.4	+2.2	8.39.8	-2,9	12.23,0	+2,5	12.54,2	+2,2	12.49,8	+3.0	11.21,3	+2,3	7.22.7	-12,3	48.54,2	+3,0	11.26	+2,8	7.12.2	-0,2	23.55,5	+7,8	65	63
12	15.51,5	+5,5	12.6.2	+0.8	11.8.5	-3.3	14.10.4	+1,0	8.36.8	-3.0	12.25.5	+2.5	12.56,6	+2,4	12.52.4	+2,6	11.23,8	+2,5	7.9	-13,7	48.52,0	+2,2	11.26,7	+2,7	7.13	-0,8	24.03	+7,5	64	
13	15.56,8	+5,3	12.7.5	+1,3	11.06,3	-2,2	14.12,2	+1.8	8.35.4	-1,4	12.28,2	+2,7	12.59	+2,4	12.55,0	+2,6	11.25,7	+1,9	6.54	-15,0	48.49,7	+2,3	11.31,2	+2,5	7.13.5	-0,5	24.10	[illegible]		
14	16.1.8	+5,0	12.8.8	+1.3	11.03.4	-2.9	14.14,2	+2,0	8.34,5	-0,9	12.31	+2,8	13.1.4	+2,4	12.58,2	+3,2	11,28	+2,8	6.38	-16,0	48.47,5	+2,2	11.33.8	+2,6	7.13.8	-0,3	[illegible]			
15	16.7.2	+5,4	12.9,6	+0,8	11.0.9	-2,5	14.17.3	+3.1	8.33,2	-1,3	12.34,4	+3,4	13.4,2	+2,8	13.1,2	+3,0	11.30,8	+2,8	6.22	-16,0	48.45	+2,5	11.36.4	+2,6	7.4.2	[illegible]				
16	16.12,5	+5,3	12,10,2	+1,2	10.57,8	-3,1	14.21	+3,7	8.32	-1,2	12.37,5	+3.1	13.7	+2.8	13.4	+2.8	11.33,2	+2,4	6.5	-17,0	48.43	+2,0	11.39.2	+2,8	[illegible]					
17	16.18	+5,5	12.12	+1,2	10.56	-1.8	14.24,2	+3,2	8.31	-1.0	12.41	+3,5	13.9,5	+2,5	13.7	+3,0	11.36,0	+2,8	5.47,5	-17,5	48.40,5	+2,5	11.41.8	+2,6						

Figure 6.19: ‘Table N. 2 Shewing the Errors of each Chronometer on Standard, every day at noon, from 21st April to the 17th May 1828’. UKHO, AO32: SFD7/7/1/7

Each chronometer is listed in this table, except the standard McCabe 167, against which Foster compared these chronometers. Figure 6.20 is a close-up of one section.



Date	McCabe		Parkinson and							
	187	Diff	543	Diff	699	Diff	799	Diff	838	Diff
1828	m s	s	m s	s	m s	s	m s	s	m s	s
17 May	+ 16,18	5,5	+ 12,12,0	1,2	+ 10,56	1,8	+ 14,24,2	3,2	+ 8,31	1,0
18	16,23,2	+5,2	12,12,8	+0,8	10,53	-3,0	14,27,8	+3,6	8,30	-1,0
19	16,28,3	+5,1	12,14	+1,2	10,50	-3,0	14,31,3	+3,5	8,28,8	-1,2
20	16,33,3	+5,0	12,15,2	+1,2	10,47,2	-2,8	14,34,8	+3,5	8,27,4	-1,4
21	16,37,8	+4,5	12,16,5	+1,3	10,44,6	-2,6	14,38,2	+3,4	8,26,5	-0,9
22	16,43	+5,2	12,17,6	+1,1	10,41,8	-2,8	14,42,8	+4,6	8,25	-1,5
23	16,48,2	+5,2	12,18,7	+1,1	10,39,2	-2,6	14,45,8	+3,0	8,24	-1,0
24	16,53,2	+5,0	12,20	+1,3	10,35,8	-3,4	14,49,3	+3,5	8,22,7	-1,3
25	16,58,7	+5,5	12,22	+2,2	10,34,3	-1,5	14,53,3	+4,0	8,21,5	-1,
26	17,4,3	+5,6	12,22	±0,0	10,30	-4,3	14,56,0	+2,7	8,19,7	-1,
27	17,9,8	+5,5	12,23,0	+1,0	10,27,0	-3,0	14,58,2	+2,2	8,17,5	-2,
28	17,15,3	+5,5	12,24,0	+1,0	10,23,8	-3,2	14,59,5	+1,3	8,15	-2,
29	17,21	+5,7	12,25	+1,0	10,21,5	-2,3	14,59,4	+0,1	8,13	-2,
30	17,26	+5,0	12,25,4	+0,4	10,18,5	-3,0	15,0,5	+1,1	8,10,5	-2,
31	17,32,0	+6,0	12,25,4	±0,0	10,15,3	-3,2	15,1,5	+1,0	8,8,5	-2
1 June	17,37,4	+5,4	12,27	+1,6	10,12,2	-3,1	15,3	+1,5	8,6,4	-2
2	17,43,2	+5,8	12,27,3	+0,3	10,8,9	-3,3	15,4,2	+1,2	8,4,2	-2
3	17,49	+5,8	12,27,7	+0,4	10,5,3	-3,6	15,4,3	+0,1	8,1,7	-2
4	17,54,5	+5,5	12,28,6	+0,9	10,2,5	-2,8	15,5	+0,7	7,59	-2
5	18,0,2	+5,7	12,29	+0,4	9,59,8	-2,7	15,5,2	+0,2	7,56	-3
6	18,5,5	+5,3	12,29,2	+0,2	9,56,3	-3,5	15,5,8	+0,6	7,52,3	-3
7	18,11	+5,5	12,29,3	+0,1	9,53,5	-2,8	15,6,5	+0,7	7,49	-3
8	18,16,7	+5,7	12,29,5	+0,2	9,50,8	-2,7	15,7,0	+0,5	7,45,6	-3
9	18,22,5	+5,8	12,29,8	+0,3	9,47,5	-2,3	15,8,3	+1,3	7,42,8	-
10	18,28,3	+5,8	12,29,7	-0,1	9,43,8	-3,2	15,9	+0,7	7,39,8	-
11	18,34,5	+6,2	12,29,5	-0,2	9,40,2	-3,6	15,10	+1,0	7,37,2	-
12	18,39,4	+4,9	12,29,2	-0,3	9,36,3	-3,9	15,11,0	+1,0	7,33,5	-
13	18,45,0	+5,6	12,28,6	-0,6	9,33	-3,3	15,12,5	+1,5	7,30	+
14	18,50,8	+5,8	12,28,3	-0,3	9,29,2	-3,8	15,13,5	+1,0	7,27	+

Figure 6.20: Detail of the daily errors. UKHO, AO32: SFD7/7/1/7

The first column in figure 6.20, which is headed by the chronometer number, is the amount of time fast or slow of the standard. The second column, the daily difference, is the difference between two daily comparisons. Fitzroy's rate book (described in detail in Chapter 7) followed the same format.

Figure 6.21 allows us to have a visual understanding of how Foster used these tables of daily differences to select which chronometers to include in determining meridian distances. The data was taken from the second column of Table 2, which thus shows the daily change in rates for each chronometer. The above example is based on the rates determined from 21 April to 8 August 1828. The lines indicated in blue represent the chronometers which Foster chose to include in the measurement of the meridian distance; chronometers P&F 699 (green), 799 (yellow), 838 (red) and Murray 620 (purple) were excluded due to the irregularity of their rates. While it is clear why Foster decided these four chronometers were not regular enough, Murray 555 and P&F 543 also evidenced alterations in rate but were deemed good enough by Foster.

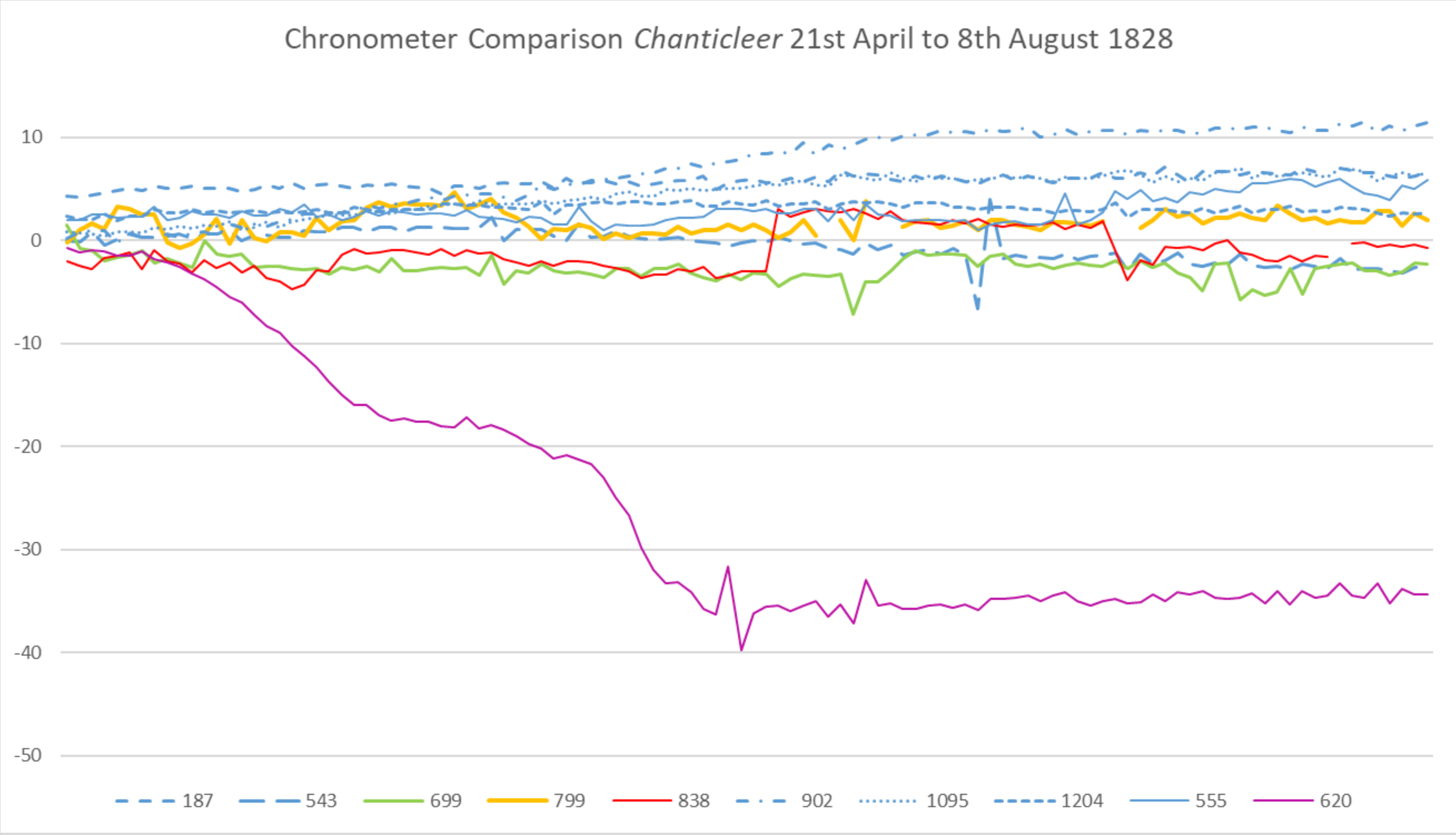
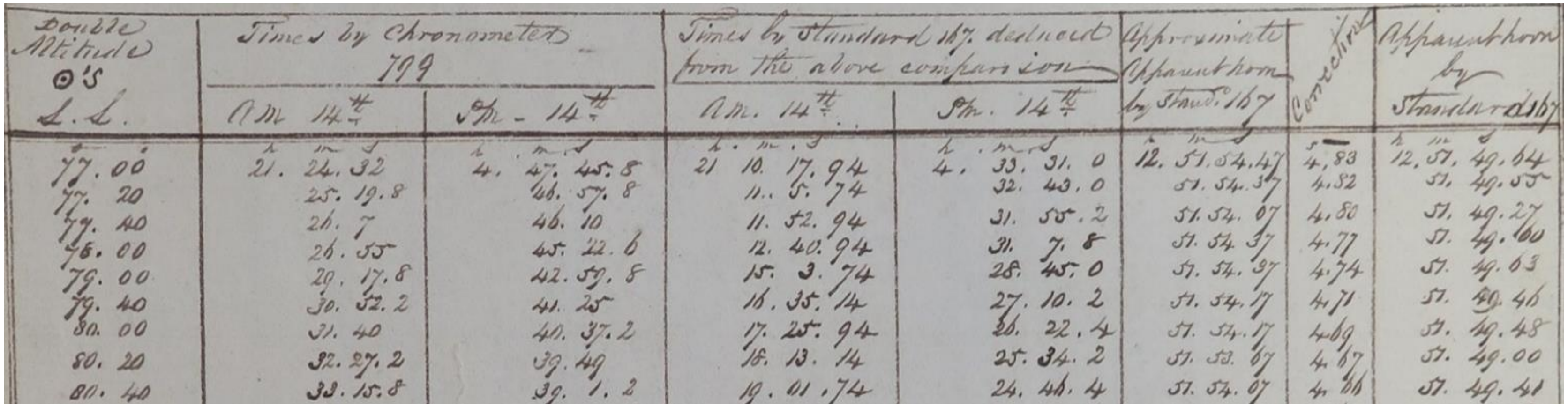


Figure 6.21: Chronometer variations between April and August 1828 on board HMS *Chanticleer*. UKHO, AO32: SFD7/7/1/7. The x-axis is the period from 21 April to 8 August, 1828; the Y-axis shows the error of the chronometer in seconds compared to the standard.

In Table 3 (figure 6.22), Foster noted the times of the observed altitudes of the Sun's lower limb (corrected for refraction, parallax and index error) from the morning and evening observations by pocket chronometer P&F 799. He then noted in the next column the times by the standard McCabe 167 by comparison. The mean of these two times (morning and afternoon) was noted in the next column and corrected for the Equation of Equal Altitudes. This led to the time of apparent noon by McCabe 167 for each double altitude. Foster observed a total of 37 sets of observations on 12 May, spending a total of one hour and twenty minutes on taking the observations; then, more time was needed to compute them. Table 3 continues on the next page, containing the same observations and calculations for 14 and 17 May. As can be seen, it was not always possible to take 37 observations and on 17 May, Foster had to make do with eight sets.

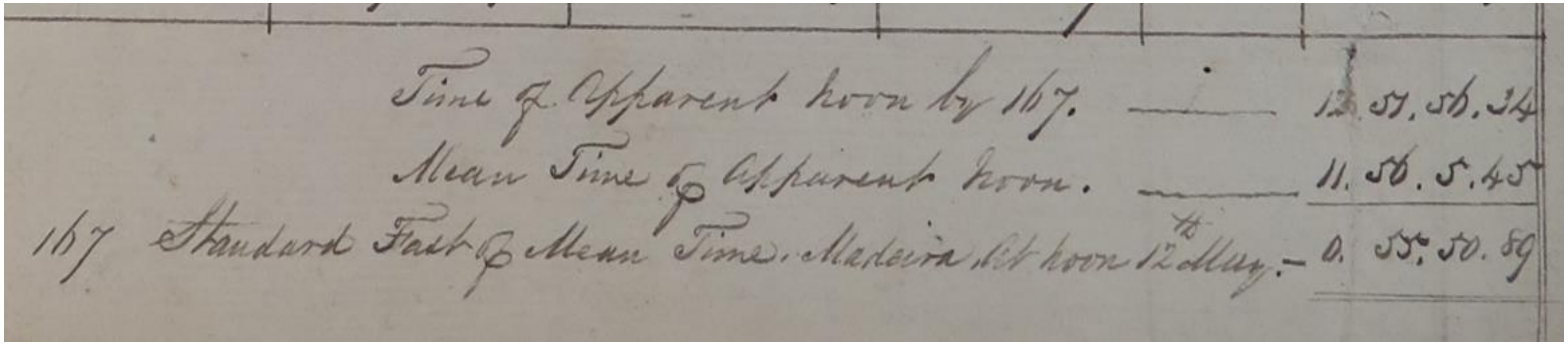
Foster determined the Mean Time of apparent noon for each day of observations and compared this to the Mean Time of apparent noon by McCabe 167. The resulting difference was the error of McCabe 167 on the Mean Time at Madeira (figure 6.23). All this data was copied directly from Foster's observation folio book.[51]

[51] Astronomical Observation Book, HMS *Chanticleer,* 1828-1831. UKHO, SFD9/12/2



Double Altitude ☉'s L.L.	Times by Chronometer 799 AM 14th	PM 14th	Times by Standard 167 deduced from the above comparison AM 14th	PM 14th	Approximate Apparent noon by Stand. 167	Correction	Apparent noon by Standard 167
	h m s	h m s	h m s	h m s	h m s	s	h m s
77.00	21. 24. 32	4. 47. 45.8	21 10. 17.94	4. 33. 31. 0	12. 51. 54.47	4.83	12. 51. 49.64
77. 20	25. 19.8	46. 57. 8	11. 5. 74	32. 43. 0	51. 54.37	4.82	51. 49.55
77. 40	26. 7	46. 10	11. 52. 94	31. 55. 2	51. 54. 07	4.80	51. 49.27
78. 00	26. 55	45. 22. 6	12. 40. 94	31. 7. 8	51. 54. 37	4.77	51. 49. 60
79. 00	29. 17.8	42. 59. 8	15. 3. 74	28. 45. 0	51. 54. 37	4.74	51. 49. 63
79. 40	30. 52. 2	41. 25	16. 35. 14	27. 10. 2	51. 54. 17	4.71	51. 49. 46
80. 00	31. 40	40. 37. 2	17. 25. 94	26. 22. 4	51. 54. 17	4.69	51. 49. 48
80. 20	32. 27. 2	39. 49	18. 13. 14	25. 34. 2	51. 53. 67	4.67	51. 49. 00
80. 40	33. 15. 8	39. 1. 2	19. 01. 74	24. 46. 4	51. 54. 07	4.66	51. 49. 41

Figure 6.22: Detail of Table 3. UKHO, AO32: SFD7/7/1/7



Time of Apparent noon by 167. —— 12. 51. 56. 34

Mean Time of Apparent noon. —— 11. 56. 5. 45

167 Standard Fast of Mean Time. Madeira at noon 12th May. — 0. 55. 50. 89

Figure 6.23: Detail of Table 3. UKHO, AO32: SFD7/7/1/7

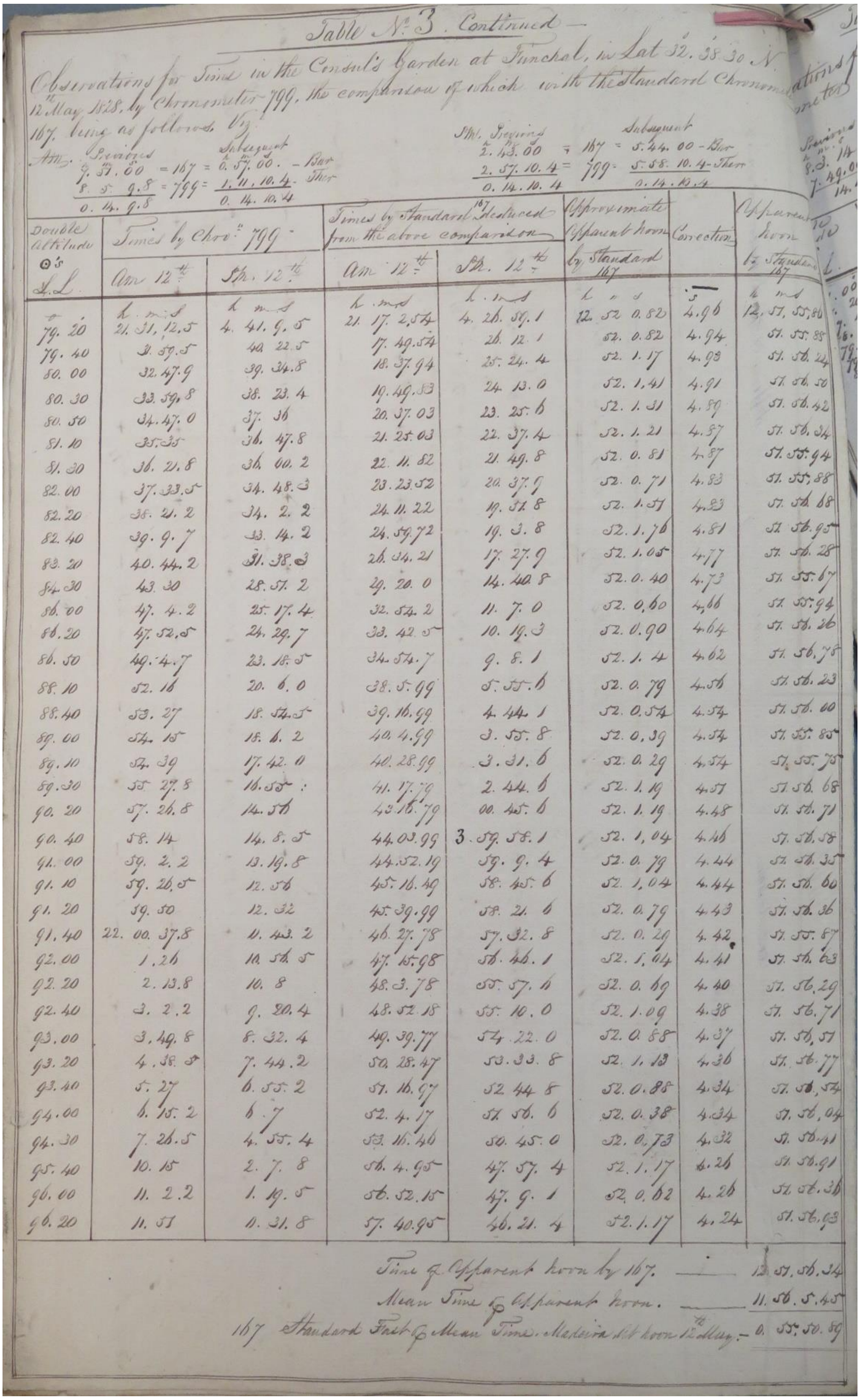


Table No. 3. Continued –

Observations for Time in the Consul's Garden at Funchal, in Lat 32. 38. 30 N. 12th May 1828, by Chronometer 799, the comparison of which with the standard Chronometer 167 being as follows, Viz:

	Previous		Subsequent	
AM.	9. 57. 00 = 167 =	0. 57. 00. – Bar		
	8. 5. 9.8 = 799 =	1. 11. 10. 4. Ther		
	0. 4. 9.8	0. 14. 10. 4		
PM.	2. 43. 00 = 167 =	5. 44. 00 – Bar		
	2. 57. 10. 4 = 799 =	5. 58. 10. 4 – Ther		
	0. 14. 10. 4	0. 14. 10. 4		

Double Altitude ☉'s L.L.	Times by Chron. 799 – AM 12th	Times by Chron. 799 – PM 12th	Times by Standard 167 deduced from the above comparison – AM 12th	Times by Standard 167 deduced from the above comparison – PM 12th	Approximate Apparent Noon by Standard 167	Correction	Apparent Noon by Standard 167
° '	h. m. s	h. m. s	h. m. s	h. m. s	h. m. s	s	h. m. s
79. 20	21. 31. 12.5	4. 41. 9.5	21. 17. 2.54	4. 26. 59.1	12. 52. 0.82	4.96	12. 57. 55.86
79. 40	31. 59.5	40. 22.5	17. 49.54	26. 12.1	52. 0.82	4.94	57. 55. 88
80. 00	32. 47.9	39. 34.8	18. 37.94	25. 24.4	52. 1.17	4.93	57. 56. 24
80. 30	33. 59.8	38. 23.4	19. 49.53	24. 13.0	52. 1.41	4.91	57. 56. 50
80. 50	34. 47.0	37. 36	20. 37.03	23. 25.6	52. 1.31	4.89	57. 56. 42
81. 10	35. 35	36. 47.8	21. 25.03	22. 37.4	52. 1.21	4.87	57. 56. 34
81. 30	36. 21.8	36. 00.2	22. 11.82	21. 49.8	52. 0.81	4.87	57. 55. 94
82. 00	37. 33.5	34. 48.3	23. 23.52	20. 37.9	52. 0.71	4.83	57. 55. 88
82. 20	38. 21.2	34. 2.2	24. 11.22	19. 51.8	52. 1.51	4.83	57. 56. 68
82. 40	39. 9.7	33. 14.2	24. 59.72	19. 3.8	52. 1.76	4.81	57. 56. 95
83. 20	40. 44.2	31. 38.3	26. 34.21	17. 27.9	52. 1.05	4.77	57. 56. 28
84. 30	43. 30	28. 51.2	29. 20.0	14. 40.8	52. 0.40	4.73	57. 55. 67
86. 00	47. 4.2	25. 17.4	32. 54.2	11. 7.0	52. 0.60	4.66	57. 55. 94
86. 20	47. 52.5	24. 29.7	33. 42.5	10. 19.3	52. 0.90	4.64	57. 56. 26
86. 50	49. 4.7	23. 18.5	34. 54.7	9. 8.1	52. 1.4	4.62	57. 56. 78
88. 10	52. 16	20. 6.0	38. 5.99	5. 55.6	52. 0.79	4.56	57. 56. 23
88. 40	53. 27	18. 54.5	39. 16.99	4. 44.1	52. 0.54	4.54	57. 56. 00
89. 00	54. 15	18. 6.2	40. 4.99	3. 55.8	52. 0.39	4.54	57. 55. 85
89. 10	54. 39	17. 42.0	40. 28.99	3. 31.6	52. 0.29	4.54	57. 55. 75
89. 30	55. 27.8	16. 55	41. 17.79	2. 44.6	52. 1.19	4.51	57. 56. 68
90. 20	57. 26.8	14. 56	43. 16.79	00. 45.6	52. 1.19	4.48	57. 56. 71
90. 40	58. 14	14. 8.5	44. 03.99	3. 59. 58.1	52. 1.04	4.46	57. 56. 58
91. 00	59. 2.2	13. 19.8	44. 52.19	59. 9.4	52. 0.79	4.44	57. 56. 35
91. 10	59. 26.5	12. 56	45. 16.49	58. 45.6	52. 1.04	4.44	57. 56. 60
91. 20	59. 50	12. 32	45. 39.99	58. 21.6	52. 0.79	4.43	57. 56. 36
91. 40	22. 00. 37.8	11. 43.2	46. 27.78	57. 32.8	52. 0.29	4.42	57. 55. 87
92. 00	1.26	10. 56.5	47. 15.98	56. 46.1	52. 1.64	4.41	57. 56. 63
92. 20	2. 13.8	10. 8	48. 3.78	55. 57.4	52. 0.69	4.40	57. 56. 29
92. 40	3. 2.2	9. 20.4	48. 52.18	55. 10.0	52. 1.09	4.38	57. 56. 71
93. 00	3. 49.8	8. 32.4	49. 39.77	54. 22.0	52. 0.88	4.37	57. 56. 57
93. 20	4. 38.5	7. 44.2	50. 28.47	53. 33.8	52. 1.13	4.36	57. 56. 77
93. 40	5. 27	6. 55.2	51. 16.97	52. 44.8	52. 0.85	4.34	57. 56. 54
94. 00	6. 15.2	6. 7	52. 4.17	51. 56.6	52. 0.38	4.34	57. 56. 04
94. 30	7. 26.5	4. 55.4	53. 16.46	50. 45.0	52. 0.73	4.32	57. 56. 41
95. 40	10. 15	2. 7.8	56. 4.95	47. 57.4	52. 1.17	4.26	57. 56. 91
96. 00	11. 2.2	1. 19.5	56. 52.15	47. 9.1	52. 0.62	4.26	57. 56. 36
96. 20	11. 51	0. 31.8	57. 40.95	46. 21.4	52. 1.17	4.24	57. 56. 03

Time of Apparent Noon by 167. — 12. 57. 56. 34

Mean Time of Apparent Noon. — 11. 56. 5. 45

167 Standard Fast of Mean Time, Madeira at Noon 12th May. — 0. 55. 50. 89

Figure 6.24: Abstracts of the Equal Altitudes taken to establish the error of McCabe 167 at Funchal on 12 May, 1828. UKHO, AO32: SFD7/7/1/7

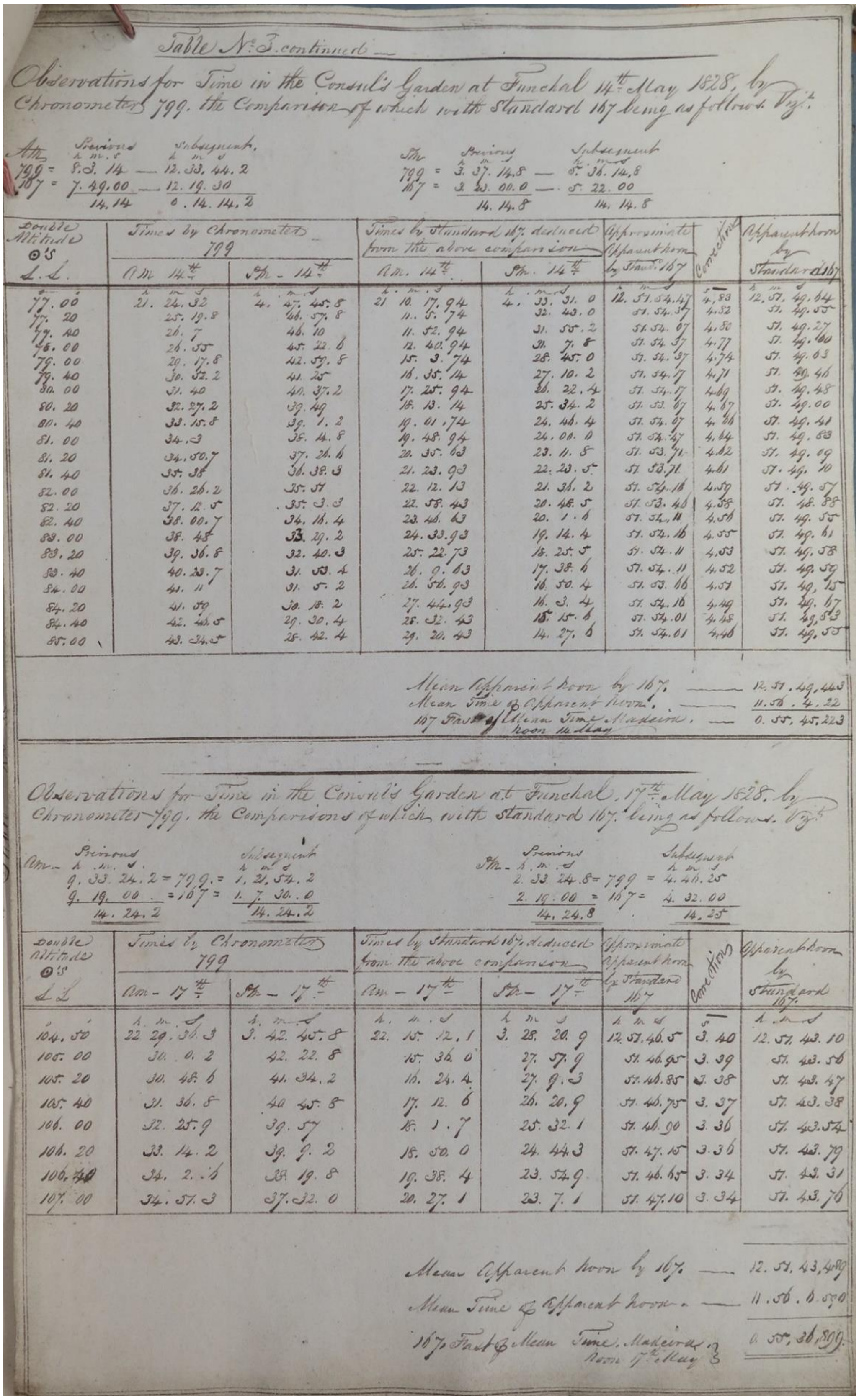


Table No. 3. continued —

Observations for Time in the Consul's Garden at Funchal 14th May 1828, by Chronometer 799. the Comparison of which with Standard 167 being as follows. Viz.

Am. Previous h. m. s. 799 = 8.3. 14 — Subsequent h. m. s. 12. 33. 44. 2
167 = 7. 49. 00 — 12. 19. 30
14. 14 — 0. 14. 14. 2

Pm. Previous h. m. s. 799 = 3. 37. 14.8 — Subsequent h. m. s. 5. 36. 14. 8
167 = 3. 23. 00. 0 — 5. 22. 00
14. 14. 8 — 14. 14. 8

Double Altitude ☉'s L.L.	Times by Chronometer 799 Am. 14th	Pm. 14th	Times by Standard 167 deduced from the above comparison Am. 14th	Pm. 14th	Approximate Apparent Noon by Stand. 167	Corrections	Apparent Noon by Standard 167
° ′	h. m. s	h. m. s	h. m. s	h. m. s	h. m. s	s	h. m. s
77. 00	21. 24. 32	4. 47. 45. 8	21 10. 17. 94	4. 33. 31. 0	12. 51. 54. 47	4, 83	12, 51. 49. 64
77. 20	25. 19. 8	46. 57. 8	11. 5. 74	32. 43. 0	51. 54. 37	4. 82	51. 49. 55
77. 40	26. 7	46. 10	11. 52. 94	31. 55. 2	51. 54. 07	4. 80	51. 49. 27
78. 00	26. 55	45. 22. 6	12. 40. 94	31. 7. 8	51. 54. 37	4. 77	51. 49. 60
79. 00	29. 17. 8	42. 59. 8	15. 3. 74	28. 45. 0	51. 54. 37	4. 74	51. 49. 63
79. 40	30. 52. 2	41. 25	16. 35. 14	27. 10. 2	51. 54. 17	4. 71	51. 49. 46
80. 00	31. 40	40. 37. 2	17. 25. 94	26. 22. 4	51. 54. 17	4. 69	51. 49. 48
80. 20	32. 27. 2	39. 49	18. 13. 14	25. 34. 2	51. 53. 67	4. 67	51. 49. 00
80. 40	33. 15. 8	39. 1. 2	19. 01. 74	24. 46. 4	51. 54. 07	4. 66	51. 49. 41
81. 00	34. 3	38. 14. 8	19. 48. 94	24. 00. 0	51. 54. 47	4. 64	51. 49. 83
81. 20	34. 50. 7	37. 26. 6	20. 35. 63	23. 11. 8	51. 53. 71	4. 62	51. 49. 09
81. 40	35. 38	36. 38. 3	21. 23. 93	22. 23. 5	51. 53. 71	4. 61	51. 49. 10
82. 00	36. 26. 2	35. 51	22. 12. 13	21. 36. 2	51. 54. 16	4. 59	51. 49. 57
82. 20	37. 12. 5	35. 3. 3	22. 58. 43	20. 48. 5	51. 53. 46	4. 58	51. 48. 88
82. 40	38. 00. 7	34. 16. 4	23. 46. 63	20. 1. 6	51. 54. 11	4. 56	51. 49. 55
83. 00	38. 48	33. 29. 2	24. 33. 93	19. 14. 4	51. 54. 16	4. 55	51. 49. 61
83. 20	39. 36. 8	32. 40. 3	25. 22. 73	18. 25. 5	51. 54. 11	4. 53	51. 49. 58
83. 40	40. 23. 7	31. 53. 4	26. 9. 63	17. 38. 6	51. 54. 11	4. 52	51. 49. 59
84. 00	41. 11	31. 5. 2	26. 56. 93	16. 50. 4	51. 53. 66	4. 51	51. 49. 15
84. 20	41. 59	30. 18. 2	27. 44. 93	16. 3. 4	51. 54. 16	4. 49	51. 49. 67
84. 40	42. 46. 5	29. 30. 4	28. 32. 43	15. 15. 6	51. 54. 01	4. 48	51. 49. 53
85. 00	43. 34. 5	28. 42. 4	29. 20. 43	14. 27. 6	51. 54. 01	4. 46	51. 49. 55

Mean Apparent Noon by 167. — 12. 51. 49. 443
Mean Time of Apparent Noon. — 11. 56. 4. 22
167 Fast of Mean Time Madeira, Noon 14 May — 0. 55. 45. 223

Observations for Time in the Consul's Garden at Funchal, 17th May 1828. by Chronometer 799. the Comparisons of which with standard 167. being as follows. Viz.

Am. Previous h. m. s. 9. 33. 24. 2 = 799. = Subsequent h. m. s. 1. 21. 54. 2
9. 19. 00 = 167 = 1. 7. 30. 0
14. 24. 2 — 14. 24. 2

Pm. Previous h. m. s. 2. 33. 24. 8 = 799 = Subsequent h. m. s. 4. 46. 25
2. 19. 00 = 167 = 4. 32. 00
14. 24. 8 — 14. 25

Double Altitude ☉'s L.L.	Times by Chronometer 799 Am. 17th	Pm. 17th	Times by Standard 167 deduced from the above comparison Am. 17th	Pm. 17th	Approximate Apparent Noon by Standard 167	Corrections	Apparent Noon by Standard 167
° ′	h. m. s	h. m. s	h. m. s	h. m. s	h. m. s	s	h. m. s
104. 50	22 29. 36. 3	3. 42. 45. 8	22. 15. 12. 1	3. 28. 20. 9	12. 51. 46. 5	3. 40	12. 51. 43. 10
105. 00	30. 0. 2	42. 22. 8	15. 36. 0	27. 57. 9	51. 46. 95	3. 39	51. 43. 56
105. 20	30. 48. 6	41. 34. 2	16. 24. 4	27. 9. 3	51. 46. 85	3. 38	51. 43. 47
105. 40	31. 36. 8	40. 45. 8	17. 12. 6	26. 20. 9	51. 46. 75	3. 37	51. 43. 38
106. 00	32. 25. 9	39. 57	18. 1. 7	25. 32. 1	51. 46. 90	3. 36	51. 43. 54
106. 20	33. 14. 2	39. 9. 2	18. 50. 0	24. 44. 3	51. 47. 15	3. 36	51. 43. 79
106. 40	34. 2. 6	38. 19. 8	19. 38. 4	23. 54. 9	51. 46. 65	3. 34	51. 43. 31
107. 00	34. 51. 3	37. 32. 0	20. 27. 1	23. 7. 1	51. 47. 10	3. 34	51. 43. 76

Mean Apparent Noon by 167. — 12. 51. 43, 489
Mean Time of Apparent Noon. — 11. 56. 6. 590
167 Fast of Mean Time, Madeira, Noon 17th May — 0. 55. 36, 899

Figure 6.25: Abstracts of the Equal Altitudes taken to establish the error of McCabe 167 at Funchal on 14 and 17 May, 1828. UKHO, AO32: SFD7/7/1/7

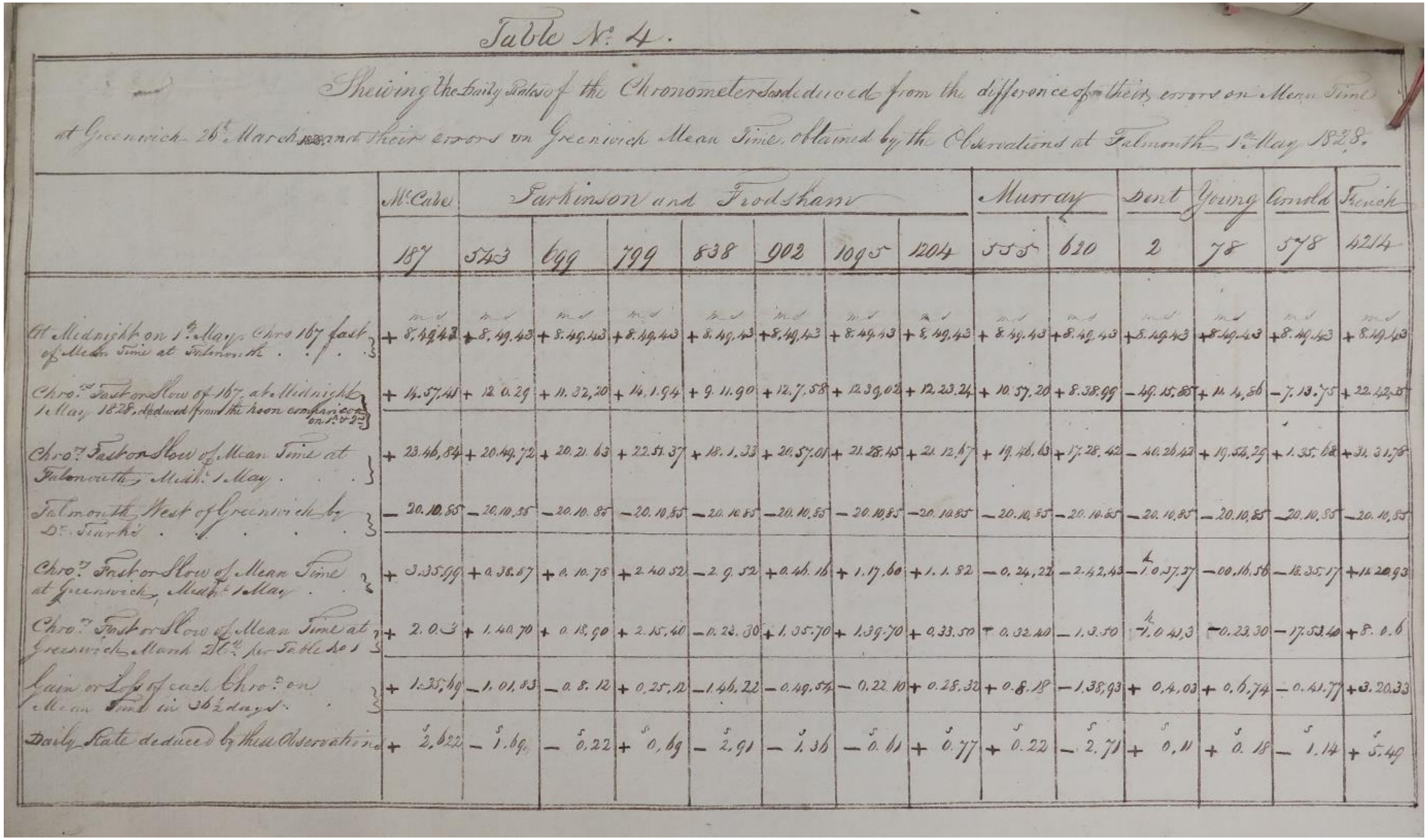


Table No. 4.

Shewing the Daily Rates of the Chronometers as deduced from the difference of their errors on Mean Time at Greenwich 26th March and their errors on Greenwich Mean Time, obtained by the Observations at Falmouth 1st May 1828.

	McCabe	Parkinson and Frodsham							Murray		Dent	Young	Arnold	French
	187	543	699	799	838	902	1095	1204	555	620	2	78	578	4214
	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s	m s
At Midnight on 1st May, Chro 187 fast of Mean Time at Falmouth	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43	+ 8.49.43
Chro. Fast or Slow of 187, at Midnight 1 May 1828, deduced from the Moon comparison on 1st & 2nd	+ 14.57.41	+ 12.0.29	+ 11.32,20	+ 14.1.94	+ 9.11.90	+ 12.7.58	+ 12.39,02	+ 12.23.24	+ 10.57.20	+ 8.38.99	− 49.15.85	+ 11.4,86	− 7.13.75	+ 22.42.5[illegible]
Chro. Fast or Slow of Mean Time at Falmouth, Midt. 1 May	+ 23.46,84	+ 20.49.72	+ 20.21.63	+ 22.51.37	+ 18.1.33	+ 20.57.01	+ 21.28.45	+ 21.12,67	+ 19.46.63	+ 17.28.42	− 40.26.42	+ 19.54.29	+ 1.35.68	+ 31.31.78
Falmouth West of Greenwich by Dr. Tiarks	− 20.10.85	− 20.10.85	− 20.10.85	− 20.10,85	− 20.10.85	− 20.10.85	− 20.10,85	− 20.10.85	− 20.10.85	− 20.10.85	− 20.10,85	− 20.10,85	− 20.10.85	− 20.10,85
Chro. Fast or Slow of Mean Time at Greenwich, Midt. 1 May	+ 3.35.99	+ 0.38.87	+ 0.10.78	+ 2.40.52	− 2.9.52	+ 0.46.16	+ 1.17.60	+ 1.1.82	− 0.24,22	− 2.42,43	− h 1.0.37.37	− 00.16.56	− 18.35.17	+ 11.20.93
Chro. Fast or Slow of Mean Time at Greenwich March 26th per Table No 1	+ 2.0.3	+ 1.40.70	+ 0.18.90	+ 2.15.40	− 0.23.30	+ 1.35.70	+ 1.39.70	+ 0.33.50	+ 0.32.40	− 1.3.50	− h 1.0.41,3	− 0.23.30	− 17.53.40	+ 8.0.6
Gain or Loss of each Chro. on Mean Time in 36½ days	+ 1.35,69	− 1.01.83	− 0.8.12	+ 0.25,12	− 1.46.22	− 0.49.54	− 0.22.10	+ 0.28.32	+ 0.8.18	− 1.38,93	+ 0.4.03	+ 0.6.74	− 0.41.77	+ 3.20.33
Daily Rate deduced by these Observations	+ s 2.622	− s 1.69	− s 0.22	+ s 0.69	− s 2.91	− s 1.36	− s 0.61	+ s 0.77	+ s 0.22	− s 2.71	+ s 0.11	+ s 0.18	− s 1.14	+ s 5.49

Figure 6.26: 'Table No. 4 Shewing the Daily rates of the Chronometers as deduced from the difference of their errors on Mean Time at Greenwich 26th March 1828 and their errors on Greenwich Mean Time obtained by the Observations at Falmouth 1 May 1828'. UKHO, AO32: SFD7/7/1/7

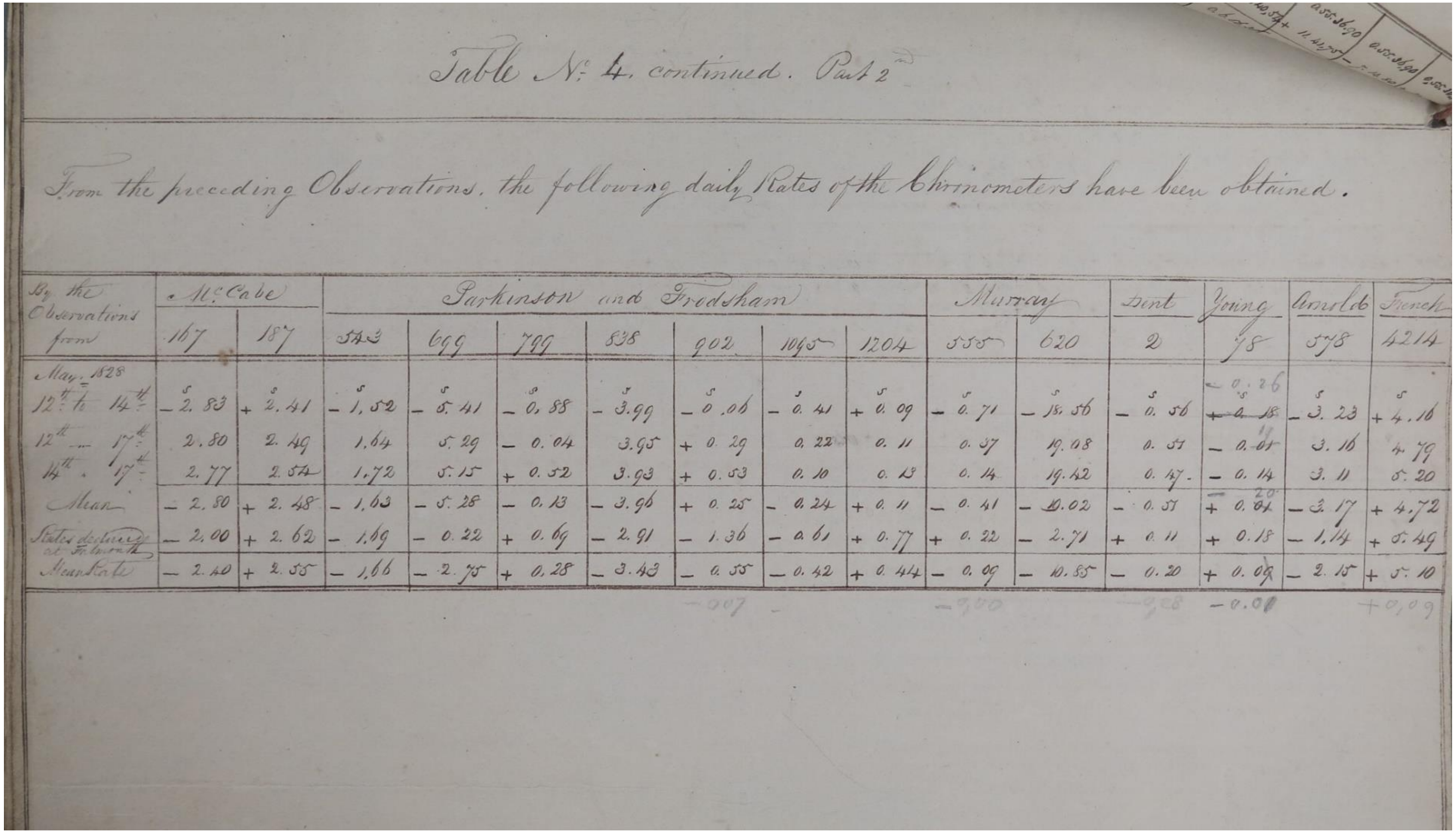


Table No. 4. continued. Part 2nd

From the preceding Observations, the following daily Rates of the Chronometers have been obtained.

By the Observations from	McCabe		Parkinson and Frodsham							Murray		Dent	Young	Arnold	French
	167	187	543	699	799	838	902	1095	1204	555	620	2	78	578	4214
May 1828															
12th to 14th	– 2.83	+ 2.41	– 1.52	– 5.41	– 0.88	– 3.99	– 0.06	– 0.41	+ 0.09	– 0.71	– 18.56	– 0.56	– 0.26 ~~+ 0.18~~	– 3.23	+ 4.16
12th – 17th	2.80	2.49	1.64	5.29	– 0.04	3.95	+ 0.29	0.22	0.11	0.37	19.08	0.51	– 0.01	3.16	4.79
14th – 17th	2.77	2.54	1.72	5.15	+ 0.52	3.93	+ 0.53	0.10	0.13	0.14	19.42	0.47	– 0.14	3.11	5.20
Mean	– 2.80	+ 2.48	– 1.63	– 5.28	– 0.13	– 3.96	+ 0.25	– 0.24	+ 0.11	– 0.41	– 19.02	– 0.51	+ 0.01	– 3.17	+ 4.72
Rates declared at Falmouth	– 2.00	+ 2.62	– 1.69	– 0.22	+ 0.69	– 2.91	– 1.36	– 0.61	+ 0.77	+ 0.22	– 2.71	+ 0.11	+ 0.18	– 1.14	+ 5.49
Mean Rate	– 2.40	+ 2.55	– 1.66	– 2.75	+ 0.28	– 3.43	– 0.55	– 0.42	+ 0.44	– 0.09	– 10.85	– 0.20	+ 0.09	– 2.15	+ 5.10
							– 0.07			– 0.00		– 0.28	– 0.01		+ 0.09

Figure 6.27: 'From the proceeding Observations, the following daily Rates of the Chronometers have been obtained'. UKHO, AO32: SFD7/7/1/7

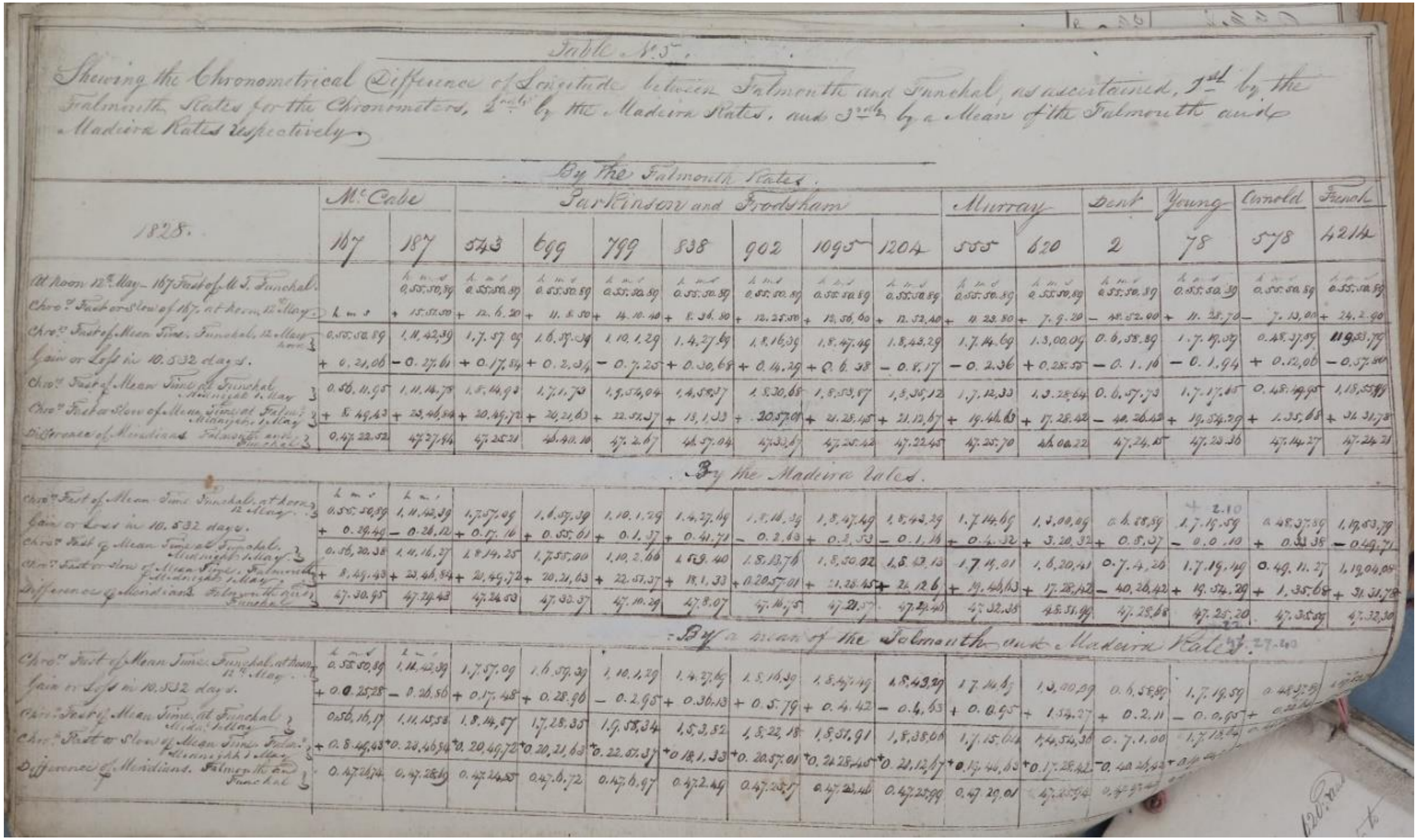


Figure 6.28: 'Shewing the Chronometrical Difference of Longitude, between Falmouth and Funchal, as ascertained 1st, by the Falmouth Rates for the Chronometers, 2ndly by the Madeira Rates, and 3rdly by a mean of the Falmouth and Madeira Rates respectively'. UKHO, AO32: SFD7/7/1/7

Table 4 shows the rates based on the calculations made at Greenwich and Falmouth (figure 6.26). Table 4 part 2 (figure 6.27) shows the rates based on the astronomical observations made at Funchal, as abstracted in Table 3. Table 4 part 2 also continued contains the rates based on the determinations at Greenwich, Falmouth and Funchal. These tables thus show how Foster determined the rates based on the observations made on shore at these three places. Using the table of comparison, Foster was able, by comparison with the standard, to determine a rate for each of the chronometers. Finally, in Table 5, Foster established a meridian distance, based on the abstracted data detailed above (figure 6.28).

The data that Foster sorted and organised in this way was important for two reasons. It was 'data in comparable, numerical form', which followed the growing trend of scientific pursuit of the nineteenth century.[52] This data was useful to others. It could be analysed, compared, adjusted and transferred to support other scientific pursuits. It also proved that the chronometric measurements had been performed adequately by the officers of the voyage. Astronomical observations could not be redone, and so trust in the abilities of the officers performing these observations remained essential. By organising and tabulating the calculations and corrections resulting from these observations, they could be examined and corrected if necessary. It was common for the officer of the voyage to perform this duty himself. Captain Owen and Lt. James Badgley spent sixteen days at Owen's residence examining and recalculating the observations made during the voyage.[53] Following Foster's death, Tiarks examined Foster's data. Tiarks corrected some errors that Foster had made in his calculations, errors that Foster would have detected himself. But Tiarks also modified the data by using different rates from Foster. He found fault with the rates Foster had determined at Falmouth, and therefore discarded those completely. Instead, rather than

[52] Godlewska, 'From Enlightenment Vision to Modern Science? Humboldt's Visual Thinking', p. 245
[53] William Fitzwilliam Owen to John Wilson Croker, 5 Market Place, 22 December, 1826. TNA, ADM1/2271

calculating the meridian distance between Falmouth and Madeira using the mean rates as had Foster, Tiarks used only the rates determined at Madeira. This data mattered: it could be moulded to support an outcome. As Tiarks illustrated: 'with a view to examine the correctness of Captain Foster's calculations, and at the same time to see whether more accordant results could be adduced, I have tried other rates, generally those nearest to the observations on which the longitudes depend'.[54] Numerical data was not objective knowledge. It was, initially, shaped by those who produced it and, later, moulded by those who would use it.

[54] Tiarks, 'Dr. Tiarks's Report on Captain Foster's Chronometrical Observations', p. 228

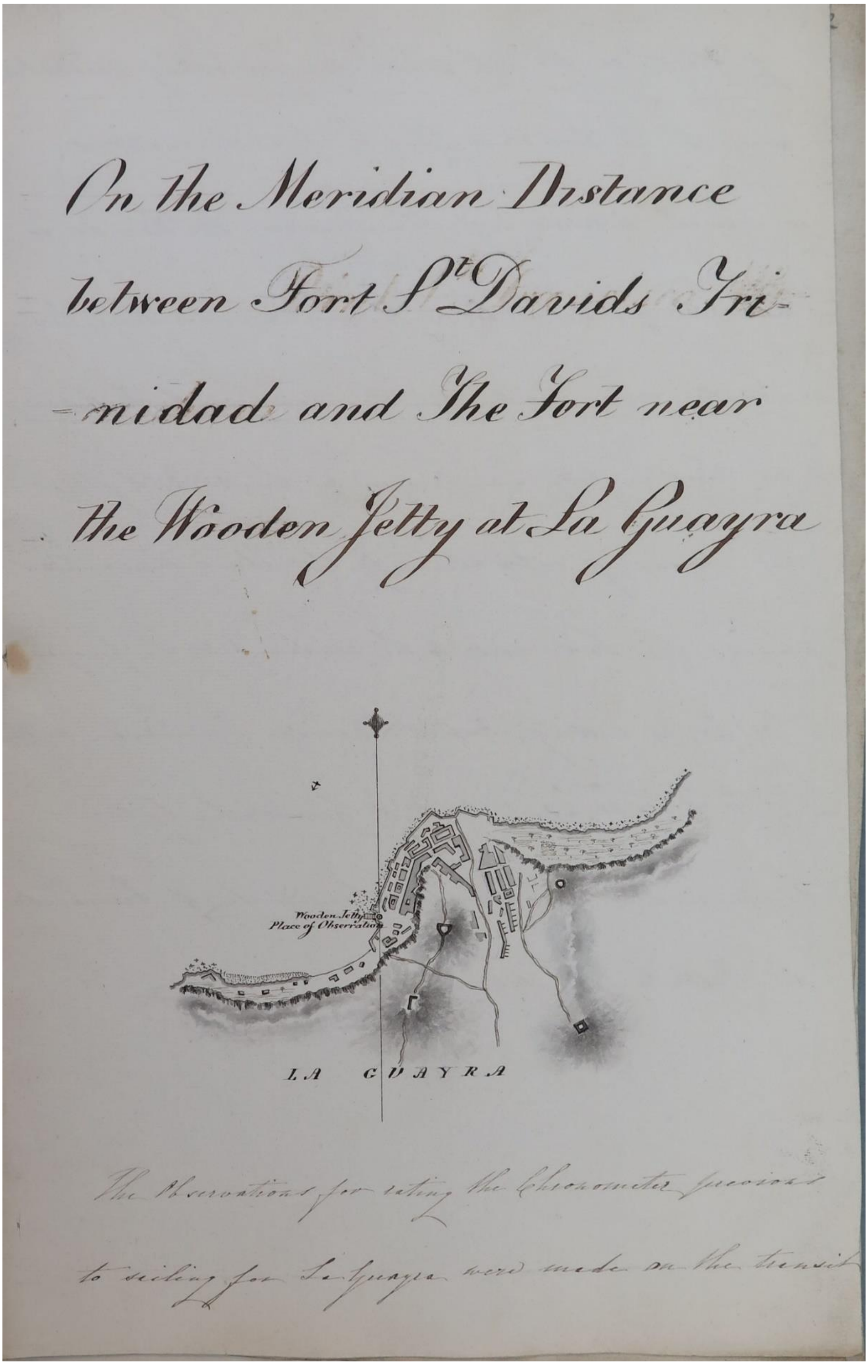


Figure 6.29: Foster’s report on the meridian distance between Trinidad and La Guayra. UKHO, AO32: SFD7/7/1/2

For each meridian distance, Foster constructed handwritten reports, although not all survive. They all have the same basic information. Figure 6.29 is the title page of a report on the meridian distance between Trinidad and La Guayra. The place of observation is detailed in a small survey for the benefit of future observations at the same spot. As each report is similar, the text from this particular document will serve as an example:

> the observations for rating the chronometer previous to sailing for La Guayra were made on the transit of stars on the 28th of November, 2nd and 5th of December near to the Protestant Church and observations by equal altitudes of the Sun, in Fort St. David's on the 7th of December, observations for the chronometer were made on the Sun in the Fort near the wooden Jetty La Guayra on the 13th & 15th of Dec. The mean of rates determined by the above observations places the Fort near to the wooden Jetty La Guayra, 21°40'24" west of Fort St. David's Trinidad, and 4h27m22s6 or 66°49'1" west of Greenwich by the determined chronometric longitude of Fernando de Noronha in 1828.[55]

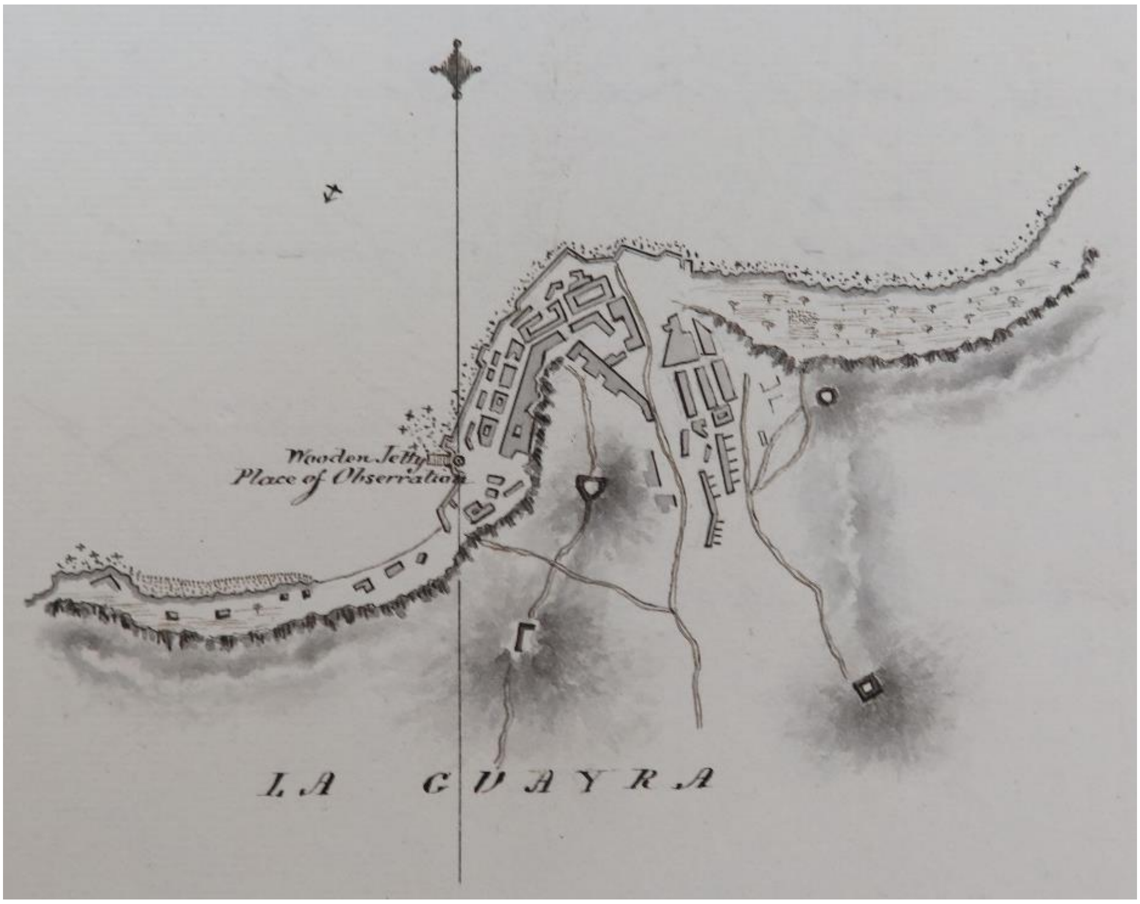


Figure 6.30: Detailed survey of the place of observation at La Guayra, HMS *Chanticleer* 1830. UKHO, AO32: SFD7/7/1/2

[55] Astronomical Observations. Foster's Observations. UKHO, AO32: SFD7/7/1/2

Many of these reports refer the reader to the tables in which the abstracted data can be found, and some reports include the latitude and the variation of the compass, but not all. The determination of the above longitude was based on the mean of nine chronometers. Foster excluded four instruments that varied too much from the mean.

What is more apparent in these reports is the importance of place. The place of practice was the actual geometrical location, where no 'two things can be in the same place at the same time', in this case the wooden jetty in La Guayra (figure 6.30).[56] This was a specific place: only here was longitude 66°49'1" west of Greenwich. But it was also a specific site of practice, or a 'practiced place', where rituals and practices were defined by users of that space.[57] At La Guayra, Foster reconstructed observatory practices, creating 'a knowledge space that transcended the boundaries of the observatory'.[58] The exact spot of observations was given in a detailed survey, since, it was important that other observers could locate it for use in their own observations, or at least, refer to this precise spot. This would also help those working in the Hydrographic Office coordinate the charts and surveys the Office received. Longitude determinations would never yield the same results, but this allowed data to be integrated into relative positions of longitude. Sabine pointed this out in 1825: 'The revised tables should contain an additional column to those in the tables at present esteemed as of the best authority, for the purpose of specifying the spot to which the geographical position refers; without such specification, it is quite superfluous to insert the data, as is now done; to seconds of space. The spots should also be selected, as far as might be possible, with reference to their conveniency [sic] of access, with instruments, from

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[56] Charles W. J. Withers and David N. Livingstone, 'Introduction: on Geography and Enlightenment', in: *Geography and Enlightenment,* David N. Livingstone and Charles W. J. Withers, eds. (Chicago: The University of Chicago Press, 1999), p. 7

[57] Withers and Livingstone, 'Introduction: on Geography and Enlightenment', p.7

[58] Ibid, p.7

vessels in the harbour'.[59] This did not always work as planned. Fitzroy, when arriving at Fernando Noronha to take observations for the chronometers, found it 'difficult to ascertain the house in which his pendulum observations were made. Not even the Governor could tell me, for he had arrived since Captain Foster's departure'.[60] The same difficulties were experienced during the 'Trigonometrical Operations' which intended to measure the difference of longitude between Greenwich and Paris in 1821 where the exact spots used for previous measurements could not be determined.[61]

These spots were crucial for calibration. They underpinned the theory on the use of time balls and could provide significant benefits for general navigation. This was because a fixed point of latitude and longitude determined for these spots meant that navigators could directly determine the error of the chronometer on local time by directly comparing the longitude as given by the chronometer to that as determined on land. The difference between the two was all that was required to calibrate the instrument. Navigators spending a week at anchor could also determine their rates with a minimal requirement of astronomical observations. All that was needed was a set of Equal Altitudes to determine the error of the chronometer at the Mean Time of the place on arrival and at departure. As the longitude of the place was known, the error of the chronometer could be readily established. Time balls simplified this process by eliminating the need for observing Equal Altitudes. Instead, officers would observe the drop of the ball.

[59] Edward Sabine, *An Account of Experiments to Determine the Figure of the Earth by means of the Pendulum Vibrating Seconds in Different Latitudes,* (London: John Murray, 1825), pp. 401-402
[60] Fitzroy, *Narrative of the Surveying Voyage,* p. 59
[61] Charles W. J. Withers, *Zero Degrees, Geographies of the Prime Meridian,* (Cambridge, Massachusetts: Harvard University Press, 2017), p. 110

As a final report, these documents provided what was considered the key information concerning a meridian distance. The place of observation was given particular attention, as anybody wishing to use this determination for their own navigation would need to observe either in the same spot, or be able to refer, via triangulation, to that particular spot. Equally important was how and when rates of the chronometers had been determined at the previous station and current station and that the mean of the two had been used for the calculation. What was *not* included is which chronometer timed the observations, which was used as the standard, and which had been chosen to determine the mean result.

Conclusion

This chapter has shown that chronometer use on Royal Navy vessels did not significantly transform navigational practices during the first decades of the nineteenth century. As longitude was constructed from a variety of observations, reductions, tables, instruments and mathematical functions, it was never made 'on the spot', but rather constructed from a distance. As such, a position of longitude by chronometer cannot be seen in isolation from lunar observations, dead reckoning, surveying and triangulation. The calculation of longitude was a time-consuming process, as officers were required to keep track of the data taken from chronometers in order that it could be analysed, corrected and formatted at a later date. Error analysis was an important part of this practice, and one that varied between users.

While at sea, the comparison tables, combined with shore-based astronomical observations, helped officers select those chronometers they considered the most reliable. Data management played an important part in this selection. As Hall pointed out, it also played a role in regulating the behaviour of officers: neatly tabulated data revealed the character of the officer. In relation to observatory practices, George Airy neatly summarised the importance of data management:

> In England, an observer conceives that he has done everything when he has made an observation. He thinks that the merely noting the passage of a star over one wire and its bisection by another, is all that can be expected from him; and that the use of a Table of logarithms, or anything beyond the very first stage of reduction, ought to be left to others. In the foreign observatories, on the contrary, and observation is considered as a lump of ore, requiring for its production, when the proper machinery is provided, nothing more than the commonest labour, and without value till it has been smelted. In them, the exhibition of results and the comparison of results with theory, are considered as deserving much more of an astronomer's attention, and demanding greater exercise of his intellect, than the mere observation of a body on the wire of a telescope.[62]

Observatory practices were never far removed from chronometer use at sea. In this case, Airy's point about reducing and comparing the data is especially relevant, as it was critical for chronometers at sea. In terms of observing on distant shores, however, this was a crucial and perhaps the most difficult part of establishing what we might think of as a 'chronometric regimen of practice' across the Royal Navy. If the longitude of a place was lacking, or incorrect, as was often the case in the early nineteenth century, local observations were the only means to establish the rate and error of the chronometers and played a critical role in calibrating the instruments. The aims of Fitzroy's, Foster's and similar voyages measuring meridian distances was to establish the positions of these ports in order to improve navigation. To accomplish this, agreement had to be reached between the varying results of many observations. The following chapter explores how these agreements were negotiated.

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[62] George Airy, 'Report on the Progress of Astronomy during the Present Century', *Report of the British Association for the Advancement of Science,* 2, (1832), quoted in: *The London and Edinburgh Philosophical Magazine and Journal of Science*, *Vol. II.* (London: Printed by Richard Taylor, 1833), p. 462

7

Negotiating Accuracy

> It happens in every profession, but probably more in the navy than in any other, that intelligent, active, practical men, are perpetually discovering something new, which may be rendered useful to the whole profession, if properly diffused.[1]

Introduction

For Captain Basil Hall whose work and words I have examined in previous chapters, diffusion of knowledge was just as important as regulation and discipline. Hall was of the view that useful discoveries at sea were entirely lost to the public. Practical men might meet at sea, 'their mutual communications are of the highest service to one another', but the exchange ended there. The 'numberless Philosophical Journals … are not in the hands of those whom it is intended to benefit'. 'Equally ineffectual', he continued, 'is the plan of directing officers to send their "Remarks" to the Admiralty' because '[as] long as the nautical reports of officers are allowed to lie neglected in the Hydrographical Office, we may be quite sure that nothing at all comparable to what might be, ever will be produced'. Hall thought this an evil that needed to be remedied because '[such] neglect infallibly chills the most zealous enthusiasm', and prevented individuals from sharing their knowledge and others from obtaining it. Without proper dissemination, the 'immense mass of interesting & important knowledge' was 'wasted'.[2] Each chapter of this thesis has opened with an epigraph by Hall, who, as I have shown, lobbied for the standardisation of navigational practices at sea in the 1820s. This

[1] Basil Hall to the Admiralty, Edinburgh, 7 April, 1820. TNA, ADM1/1956
[2] Ibid

chapter shows that Henry Raper (1799-1859) was also pivotal in attempts to standardise navigational practices involving chronometers from the late 1830s.

Raper's *Practice of Navigation and Nautical Astronomy* first appeared in 1840 and was a standard work on navigation until 1920 when the twenty-first and final edition was published. For this work, Raper received the Gold Medal from the Royal Geographical Society. The East India Company and the Admiralty issued copies of his *Practice* to their ships. Raper's authority on navigation resulted from his own naval experience. After serving with his father, Admiral Henry Raper, he studied at the Royal Naval College from 1812 to 1814, passing with distinction and earning the silver medal for proficiency in mathematics. Raper's determination to improve navigation may have been influenced by his experience on board HMS *Alceste*, which struck a reef during an expedition on which he served as a midshipman. During the voyage, Captain Murray Maxwell found that the charts of Western Korea had erroneously placed the reef 130 miles farther east. Serving later under surveyor and astronomer William Henry Smyth in the Mediterranean, Raper was put in charge of the chronometers, where he 'had exceptional opportunities for the scientific study of navigation, nautical astronomy, and surveying'.[3] Raper would become an authority on navigation and took up Hall's calls to regulate and discipline the use of chronometers at sea. In Raper's view, the 'ultimate perfection of hydrography demands very different proceedings from those which have sufficed to collect together the first rough materials of the outline, and can evidently be effected solely by the chronometric measurement of small distances, finally depending upon certain points determined by unimpugnable astronomical observations'.[4]

[3] J. K. Laughton, revised by Derek Howse, 'Henry Raper (1799-1859)', *Oxford Dictionary of National Biography,* (online ed.), Oxford University Press. Last accessed 17 September, 2020: https://doi-org.ezproxy.is.ed.ac.uk/10.1093/ref:odnb/23144

[4] Henry Raper, 'Remarks on the Mode of Determining Longitude', *Nautical Magazine*, May, (1839), p. 320

The work of Hall and Raper provides the focus to this chapter. Building upon the evidence of chapter 6, the chapter looks at how data collected at sea was analysed and processed and subsequently communicated to users. The rate and comparison books recorded only the 'raw' data produced by chronometers. Useful knowledge followed from processing this data, which primarily involved determining the rate and error of each chronometer, from which points of longitude were deduced. Officers were familiar with the instruction in navigation manuals to 'find the Errors and Rates of Chronometers', but a rate or error was not easily 'found'.[5] Rather, it was the result of complex judgments about something which was never constant: always negotiated, never found.

This chapter shows that the study of chronometric longitudes needs to be taken further than just the determination of rate and error in order to understand how individual determinations interacted and to what effect. A focus on the voyage may show how determinations were negotiated in the field (see also chapter 6), but misses the interplay between the various outcomes of the voyage and how consensus was reached based on data that accumulated in the Hydrographic Office. This data was first collected on board ship, where an agreement was required between the instruments and methods used. With the increase in the number of scientific and surveying voyages came an increase in the number of determinations that required evaluation. Each new voyage carried determinations produced by previous expeditions. Encounters between servicemen during these expeditions led to exchanges of nautical knowledge and to additional data which was incorporated with those already in their possession and with that produced on the voyage. Of the two methods (astronomical and chronometrical), neither could give the absolute longitude at sea, 'for no astronomical observations taken at sea can be implicitly depended upon within at least one

[5] Edward Riddle, *Treatise on Navigation and Nautical Astronomy,* (London: Baldwin, Cradock, and Joy, 1824), p. vii

minute, and the chronometer, in consequence of not preserving exactly the same rate, ceases, after some days, to afford the true longitude of the ship. Since, therefore, the absolute longitude of the ship herself cannot be determined with certainty, the knowledge of the precise longitude of any position, as a rock, or a shoal, which she may be near, is but of little service'.[6] Basically, whether making *absolute* astronomical observations of longitude on shore or measuring *relative* chronometrical differences of longitude by ship, no two measurements would ever agree. This meant, Raper continued, 'the whole mass of positions is kept in a state of perpetual fluctuation, from which it is impossible that universal precision can ever be obtained'.[7] Every data set that the Hydrographic Office received was slightly different from those previously gathered there. Absolute universal precision may not have been attainable, but by analysing the accumulated data, agreement could be achieved.

This chapter looks at how these different data sets were constructed, compared, evaluated, and agreed upon. To be of any use, local determinations had to be analysed and used to support global navigational science. This could only be done by reaching agreement because, as Raper pointed out, no two determinations of longitude were ever the same. Accuracy 'was always a relative achievement'.[8]

The first section explores the important relationship between the ship and the shore. I show how longitude determinations made by previous expeditions helped officers judge the reliability of their own practices. This could be done by evaluating how the information gathered by users 'retain(ed) integrity across time, space, and local contingencies'.[9] Trust in

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[6] Henry Raper, *The Practice of Navigation and Nautical Astronomy,* (London: J. D. Potter, 1842), sixth edition, p. 378

[7] Raper, *The Practice of Navigation,* sixth edition, p. 379

[8] Charles W. J. Withers, *Zero Degrees, Geographies of the Prime Meridian,* (Cambridge, Massachusetts: Harvard University Press, 2017), p. 114

[9] Joan H. Fujimura, 'Crafting Science: Standardized Packages, Boundary Objects, and "Translation"', in: *Science as Practice and Culture,* Andrew Pickering, ed. (Chicago and London, University of Chicago Press, 1992), p. 172

the measurements became linked to the user's ability to protect the instruments against the vagaries of the voyage, the method of calculating the rate and error, the ability to detect and exclude unreliable instruments, and ultimately, the agreement of their outcomes with those of others. In chapter 5 I showed how users adhered to hierarchies of instruments, where some were trusted more than others. Here I show how different users' perception of the reliability of their instruments in relation to other methods of determining longitude affected their practices. That shore-based astronomical observations provided a check on the chronometers is well known, but the extent to which they were considered necessary was a matter of personal judgement.

The second section looks at the shore as a 'place of knowledge', a field-site and a truth-spot. The example taken, Deception Island (an island in the South Shetland Islands, close to the Antarctic Peninsula, which was a whaling station in the nineteenth century), where Foster spent nearly two months making astronomical observations, was remote and the weather unfavourable. Replicating observatory practices in these conditions was challenging and only a few individuals had access to the resources required to do so. Being in the field demonstrated 'the inescapability of variation and improvisation, even in those that were following instruction'.[10] The remoteness of the location led to variation through operational variance, as did the 'independence of those who worked at a distance'.[11] Despite this, the remoteness of the field-site also led to observers there gaining authority: 'being there', as Gieryn wrote, 'becomes an essential part of claiming authority for an observation or discovery'.[12] It was the immersive nature of the field that allowed this to happen, as field scientists developed 'embodied ways of feeling, seeing, and understanding', experiences that

[10] Sophie Waring, *Thomas Young, the Board of Longitude and the Age of Reform,* Unpublished PhD, University of Cambridge, (2014), p. 121
[11] Ibid, p. 121
[12] Thomas F. Gieryn, 'City as Truth-Spot: Laboratories and Field-Sites in Urban Studies', *Social Studies of Science,* 36, (2006), p. 6

others elsewhere did not.[13] Based on precision instruments and instructions supplied by the Board of Longitude and the Royal Society, the knowledge produced here transcended the contamination of place by establishing and maintaining credible and repeatable observatory practices. Tresch has argued that while instruments could and did respond to their environmental circumstances (heat or cold could affect their operation), agreement 'between the field instrument and the master instrument, often located in the observatory, [fixed] the instrument's action within a defined range of values, providing the shared and stable background needed to make local difference communicable'.[14] The field site thus also followed the standardised practices and disciplines of the observatory.

Astronomical observations determined the longitude on shore; chronometrical longitudes would connect these to other places. The astronomical observations on shore also served to calibrate the chronometers. This seemingly straightforward affair, a distance measured chronometrically with a large number of instruments, still did not guarantee a definitive and reliable outcome. Instruments were made to agree by their operators including and excluding specific results, and by selectively applying rates and errors that would best reflect the desired agreement between instruments. How this should be done could and did differ between users. By examining two meridian distances measured on the voyage of the *Chanticleer*, I show how measurements depended on different criteria and how individuals could interpret the same data differently.

The final section examines how these determinations were accumulated and interpreted after the voyage, and how they fed into new determinations of voyages setting out. The trust placed in different methods of measurement is once again important here.

[13] Gieryn, 'City as Truth-Spot', p. 6

[14] John Tresch, 'Even the Tools will be Free: Humboldt's Romantic Technologies', *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture,* David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), p. 271

Raper defined *absolute* positions as those determined astronomically and *relative* positions as those determined chronometrically. Raper believed that these two aspects would lead to the 'ultimate perfection of hydrography', which would be attained 'solely by the chronometric measurement of small distances, finally depending upon certain points determined by unimpugnable astronomical observations'.[15] Raper termed these points secondary meridians (as only Greenwich or Paris could be considered the zero, or prime meridian) which would serve as a 'regulating meridian of a survey'.[16] Raper thus set out to establish fixed longitudes for a total of eighteen secondary meridians, based on information accumulated at the Hydrographic Office. These were 'determined nearly enough for present purposes' but would require 'long series of astronomical observations' to settle their positions.[17] In addition to hierarchies of instruments, there was a clear hierarchy in technique: only extensive astronomical observations could settle the longitude of Raper's secondary meridians. This section shows how Raper negotiated accuracy from the variety of voyages and methods previously employed to determine longitude. Accuracy was not achieved solely through precision instruments and standardised practices, but also through agreement.

Negotiations between ship and shore

On 24 May 1819, the crew of the *Hecla* spotted Rockall, an islet located west of the Outer Hebrides. The chronometers had last been rated at Somerset House, on May 7, and Sabine used a previous determination of the islet to gauge their accuracy: 'at 30 minutes past noon we saw Rockall, as we expected, but bearing rather further to the Westw[d] (SW ½ W by comps)

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[15] Raper, 'Remarks on the Mode of Determining Longitude', p. 320

[16] Henry Raper, 'On the Necessity of Adopting Secondary Meridians', *Nautical Magazine,* June, (1839), p. 399

[17] Henry Raper, *The Practice of Navigation and Nautical Astronomy*, (London: R. B. Bate, 1840), p. xi

of what our chron[rs] had given us. Its distance was about 13 miles. As I know from experience how excellent an observer Capt[n] Capel is, I consider this as a confirmation of our chronometers being a mile or two to the Westw[d] of the truth'.[18] Captain Thomas Bladen Capel[19] had determined the position of Rockall in 1810, by the mean of sixteen lunar observations taken in July and August and by the mean of three chronometers.[20] Sabine placed more trust in Capel as an observer than the six chronometers they carried ('an excellent & superior assortment' according to Parry), which had been rated only two weeks previously for a duration of five weeks.[21]

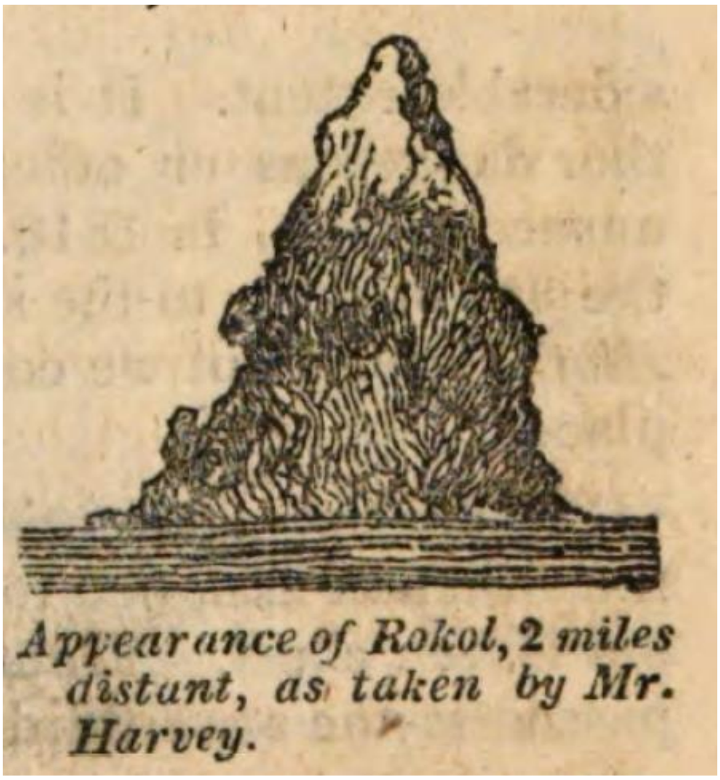

Figure 7.1: Rockall, depicted in John Purdy's *Memoir,* 1825.

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[18] HECLA: Journal with Appendix kept by W E Parry TNA ADM55/157/1 24 May 1819

[19] Captain Thomas Bladen Capel of HMS *Endymion* (1776-1863). Capel had a distinguished naval career after serving as an officer during the French Revolutionary War, the Napoleonic Wars and the War of 1812. Basil Hall accompanied this expedition on board HMS *Endymion* as a lieutenant.

[20] John Purdy, *Memoir, Descriptive and Explanatory, to Accompany the New Chart of the Atlantic Ocean, and Comprising Instructions, General and Particular, for the Navigation of that Sea,* (London: R. H. Laurie, 1825), p. 241

[21] Letter from William Edward Parry to his Parents, 22 January, 1819. SPRI, GB 15: MS438/26/46

For the purpose of navigation, however, this close encounter between observations was 'striking proof of the infinite value of chronometers at sea, [that] the certainty with which a ship may sail directly for a single rock like this, rising like a speck out of the ocean, and at the distance of forty-seven leagues from any other land'.[22] This enthusiasm must be tempered, however, with the fact that 'single rocks' required accurate charting before one could sail directly towards their destination. While navigating safely with chronometers was one thing, accurately charting a 'rising speck out of the ocean' was another, and required more than just a good chronometer.

As the journey continued, lunar observations were made to check the reliability of the chronometric determinations. These were taken in June and August and Sabine gave each chronometer a new rate based on the calculations. Sabine confirmed the validity of these rates when the ships reached their winter station. In September that year, at Melville Island, the ships were secured for the winter and Sabine compared the chronometrical longitude with the 'true longitude', this being a point determined by 6862 lunar observations and connected by a survey.[23] He concluded that 'the error of the chronometrical longitude … proved in distance less than a geographical mile; an amount so trivial' that it needed no 'further consideration' and that the rates 'at the expiration of four months, had produced so very close an accordance with the result of so great a number of lunar observations, were judged to require no further correction'.[24] In the period between May and September, from departure to the arrival at Melville Island, two checks were thus carried out for the chronometers.

[22] William Edward Parry, *Journal of a Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific; Performed in the years 1819-20, in His Majesty's Ships* Hecla *and* Griper (London: John Murray, 1821) p. 4
[23] Parry, *Journal of a Voyage 1819-1820*, Appendix, p. vi
[24] Ibid, pp. vi-vii

In the first instance, Captain Capel's observational skills outweighed the careful rating of the instruments at Henry Browne's house in London. This was because Sabine anticipated an alteration in the rates of the chronometers following departure from London. Secondly, the chronometrical longitude that Sabine referred to had been established using rates determined by lunars taken at sea in June and August. This corrected longitude was compared to that determined by 6,862 lunar observations taken on shore at Winter Harbour, and so was considered good enough. Here, the volume of data served to confirm the observations made.

Sabine's faith in the chronometers could only be confirmed by lunar observations, as these verified the accuracy of the determined longitudes. This can be seen in the minutes of a meeting between the Board of Longitude and officers from the voyage on 27 November 1820. In September 1819, the *Hecla* and *Griper* had sailed beyond 110º west within the Arctic Circle and so, according to the 1818 Longitude Act, were entitled to a reward of £5000.[25] At the meeting were Parry, Sabine, Liddon and Hoppner to 'prove their claim to the said reward'. The Board wanted to know, amongst other details, which longitude was reached and how this was established. Liddon specified a longitude of 113° 46'15" 'by the mean of the timepieces'. Sabine stated the longitude as 'certainly beyond 113º' based on the accurate observations taken at Winter Harbour. The longitude at Winter Harbour was '110°48'29" by the mean of 6,862 lunar observations taken by myself and other officers. The rates of 5 chronometers were determined by 3 month's lunar observations, and after 3 month's they agreed with the true time observed at the Calton Hill within less than 3 seconds of time, or

[25] 'A Bill for more effectually discovering the Longitude at Sea, and encouraging attempts to find a Northern Passage between the Atlantic and Pacific Oceans, and to approach the Northern Pole, 9 March 1818'. Quoted in: Trevor H. Levere, *Science and the Canadian Arctic: A Century of Exploration, 1818-1918,* (Cambridge: Cambridge University Press, 1993), p. 44

35” of longitude’.[26] Hoppner and Parry both corroborated the determinations but without specifying the observations on which they were based.[27] From these testimonies, it is clear that although the chronometers were used to determine the longitude, the credibility of the chronometric results relied on the celestial observations taken on shore: extensive lunar observations at Winter Harbour and further observations taken at Calton Hill.

For Parry and Sabine, the rates determined at sufficient intervals (a maximum of twelve weeks was advised) were considered adequate as ‘the error of the chronometrical longitude, using the corrected rates ascertained by means of the lunars of June and August, proved in distance to be less than a geographical mile; an amount so trivial, that is was not deemed necessary to pursue its further consideration; and rates … were judged to require no further consideration’.[28] On the second voyage, Fisher was more wary as he believed magnetism had a pronounced effect on chronometer rates. He was one of a few writers in the early nineteenth century to assert that the iron on board a ship influenced the rates of chronometers.[29] Opinions varied on this. Sabine insisted in the case of magnetism and chronometers that the results from Parry’s first voyage proved that ‘a more decisive result in the negative [could not] have been obtained’.[30] Sabine believed it had ‘been overlooked by many *whose ingenuity has been exerted in devising contrivances to remedy an evil which has no practical existence*’.[31] Owen also disagreed with Sabine. Firstly, in Owen’s opinion, chronometers could not be rated often enough. Secondly, Owen considered lunar

[26] Confirmed minutes of the Board of Longitude, 1802-1823. Minutes 27th November, 1820. CUL, RGO 14/7, f. 2:324
[27] Confirmed minutes of the Board of Longitude, 1802-1823. Minutes 27th November, 1820. CUL, RGO 14/7, ff. 2:321-330
[28] Parry, *Journal of a Voyage 1819-1820,* Appendix, pp. vi-vii
[29] Randell C. Brooks, 'Magnetic influence on chronometers, 1798 - 1834: A case study', *Annals of Science,* 44:3, (2006), pp. 245-264
[30] ‘Marine Chronometers, and the Currents of the Ocean’, *The Kaleidoscope: or, Literary and Scientific Mirror,* 6 September, (1825), p. 78
[31] Ibid, p. 78, original emphasis

observations obtained at sea unsatisfactory for determining rates. But Owen also pointed out that he was not against the lunar method for determining longitude, and that he recognised its utility on longer voyages.[32]

On the following voyage to find a North-West Passage, Fisher received instruction from the Admiralty to 'keep an accurate register of all the observations that shall be made, precisely in the same forms, and according to the same arrangement, that were followed by Captain Sabine on the late voyage'.[33] Where Sabine was satisfied with the rates corrected by lunars in June and August, which were confirmed at Winter Island, Fisher was less convinced of the stability of a chronometer's rate. Guided by his belief in the effects of magnetism on chronometers, Fisher applied more checks on the chronometers than his predecessor. Sabine applied a correction for the rates of the chronometers by lunar observations, leading to an interval in which the same rate was applied over seventeen weeks, from 6 May to 6 September 1819. At sea, Fisher used lunar observations to rate the chronometers, in intervals 'never exceeding twelve weeks'.[34] Even though this was a good way to keep a check on the chronometers, Fisher believed that 'the most favourable opportunities' to determine the chronometric error was provided by 'fixing the meridian of the ships' at winter quarters and through a great number and variety of observations.[35]

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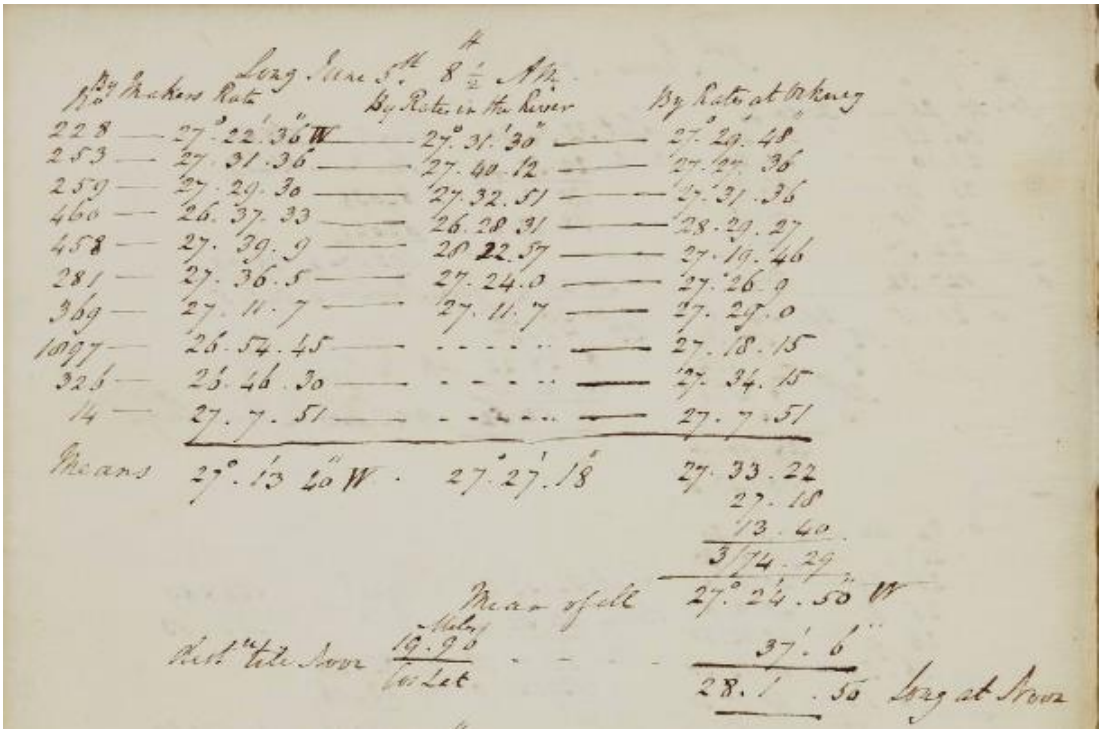
[32] Richard Owen, 'An Essay on the Management and Use of Chronometers', in: *Tables of Latitude, and Longitudes by Chronometer*, William Fitzwilliam Owen, (London; Duckworth and Ireland, 1827), p. 33
[33] William Edward Parry, *Journal of a Second Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific Performed in the Years 1821-1822-1823*, (London: John Murray, 1824), pp. xxvii
[34] William Edward Parry, *Appendix to Captain Parry's Second Voyage for the Discovery of a North-West Passage from the Atlantic to the Pacific, performed in His Majesty's Ships* Fury *and* Hecla *1821-22-23*, (London: John Murray, 1825), p. 6
[35] Parry, *Appendix to Captain Parry's Second Voyage*, p. 7



Long. June 5th 8½ AM

No.	Makers Rate	By Rate in the River	By Rate at Orkney
228	27°22'36"W	27°31'30"	27.29.48
253	27.31.36	27.40.12	27.27.36
259	27.29.30	27.32.51	27.31.36
460	26.37.33	26.28.31	28.29.27
458	27.39.9	20.22.57	27.19.46
281	27.36.5	27.24.0	27.26.9
369	27.11.7	27.11.7	27.29.0
1097	26.54.45	......	27.18.15
326	25.46.30	......	27.34.15
14	27.7.51	......	27.7.51
Means	27°13'20"W	27°27'18"	27.33.22

27.18
13.40
3/74.29
Mean of all 27°24'.50"W
Dist. tile Noon 19.9 Miles to Let ... 37'.6"
28.1.50 Long at Noon

Figure 7.2: Longitude on 5 June using the mean of three different rates. NMM, FIS/7.

Fisher took a different approach to Sabine. We can find evidence of this early on in the voyage. On June 5, 1821, one month after departure, Fisher readjusted the rates of the chronometers twice. He determined the longitude on that day by the mean of three rates: those supplied by the makers, by rates determined in the river (probably the Thames), and by rates determined at Orkney (figure 7.2). Each determination was given equal weight in the calculation. How Fisher determined the rates in the river is unknown, but the rates at Orkney seem to have been determined by altitudes taken on shore, although he did not note the method, calculation and rates attributed in his observation book. During the passage to Hudson Strait, Fisher, like Sabine, also took lunar observations during the summer months to rate the chronometers. Based on these observations, the rates were once again corrected. Rather than assign a rate for the whole period, Fisher divided the alteration in rate according to the fluctuations as shown in the daily comparisons. Fisher therefore corrected for a progressive alteration in rate in this way, rather than just using the mean within an interval. Both Sabine and Fisher used the comparison tables to check the going of the chronometers, but only Fisher appeared to use them to determine which rate should be allowed. The example of chronometers P&F 228 will serve as an example of Fisher's approach:

> No. 228 certainly took up a much smaller gaining rate immediately after its being put on board: about the 18th of May it began to gain still less, by the mean of the five other watches, about $1^s.3$ per day. From the 29th June, it again gained more, by nearly the same quantity. The rates allowed are
>
> | | |
> |---|---|
> | 26th April till 18th May | $+2^s.7$ |
> | 19th May ,, 29th June | $+1^s.4$ |
> | 30th June ,, 18th July | $+2^s.62$[36] |

For the following season of navigation, Fisher divided the period into two intervals, one just under four weeks and one of nine weeks. On this occasion, Fisher applied a single mean rate to each chronometer for both intervals. This was because he considered the first interval a short one. His justification for the second interval was that as in 'the weekly Table, No. V, there appears to have been no material irregularity in the going of the watches upon each other, one rate has been applied to each during the second interval'.[37] The results given by the mean of the chronometers thus varied according to the users and how they decided to divide the rates given to each period, which would result in slight variations in the positions of longitude measured.

This returns us to the importance of place and to the geography of science: where a longitude determined on shore was seen as more accurate and was a point against which the chronometers were checked. But the determination of place varied. Sabine had great faith in both chronometers and lunar distances. Fisher was more cautious. Both took numerous lunar observations during the winter stop at the observatories they established. But where Sabine used only lunar distances to determine the meridian of their winter stop, Fisher also observed twelve eclipses of Jupiter's Satellites. Not all observations were equal. In the publication of the second voyage, Parry gave two potential longitudes for the observatory at

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[36] Parry, *Appendix to Captain Parry's Second Voyage*, p. 9

[37] Ibid, p. 15

Winter Island, where the ships were stationed during the winter of 1821-22. The longitude published on the chart was calculated by 'considering each eclipse of the same value as one set of Lunar Observations' and gave the result as 83º09'49.6". The longitude by 944 Lunar Observations was 83º10'02.16", and by 12 eclipses of Jupiter's Satellites 82º53'21.5". By counting each set of lunar distances equal to one eclipse, the result is closer to the observations based on the lunar distances. But another calculation was possible based on the mean between the two methods, by not considering one of *more* value than the other, which would put the observatory of Port Bowen in 83º01'41.83", a difference of 8'07.8" degrees of arc, or 8.2 geographical miles. Parry did not make this judgement himself, but decided that 'should the last method of deducing the Mean be considered more just, the Longitudes in the Charts, for this part of the coast will be subject to a correction of -8'07.8".'[38] In addition to the above mentioned observations, Fisher also observed Right Ascensions of the stars and Moon, and of the Sun and Moon and by occultations of fixed stars, but as these required comparisons with corresponding observations at Greenwich, they were not taken into account by Parry.

Foster, 'observer extraordinaire' as he was, took this even further. During the winter of the 1824-25 expedition, he calculated the position of the winter observatory at Port Bowen based on the following measurements:

> Mean latitude of the observatory at Port Bowen, [was determined] by 90 observations of the stars with the repeating circle: 73°13'39''39 North.[39]
> Longitude:

By 6 occultation's of fixed stars by the Moon	88.54.52,4 West
By 23 transits of the Moon	88.57.30,99
By 21 Eclipses of Jupiter's satellites	88.52.08,85
By 620 lunar distances (viz 310 * east, & 310 * west of Moon)	88.54.22,41
By 9 chronometers	88.55.08,1
Received longitude being the mean of the above:	88.54.48,55

[38] Parry, *Appendix to Captain Parry's Second Voyage*, p. 93
[39] HECLA: Journal kept by Captain W E Parry. Arctic exploration: North-West Passage. Full and detailed account of the expedition, with several sketches. TNA, ADM55/67/1, p. 76/141

Foster considered all the methods used to have equal merit and so gave each equal weight in the mean. The longitude derived from nine chronometers was also included in the mean. For Foster, the fact that they lay within agreement of the other celestial observations was further testament to the correctness of the result. The detail and extent of these land-based observations show the importance of determining an accurate base for the charts. But the three above examples also highlight how each observer had his own preferences as to how this should be done. Establishing the longitude of an observatory was not just a negotiation between observers and their methods: some methods or determinations were given more weight than others.

What we learn from this is, firstly, that the position of the ship was continuously evaluated by more than just the methods of dead reckoning, chronometers or lunar distances. Longitude points on land, even when that was a tiny rock off the coast of Scotland and had been determined a decade earlier by another voyage, helped officers evaluate the reliability of their measurements. Officers determined the longitude on land each winter, to serve as a base for their surveys and to calibrate the chronometers. Secondly, although calibration was an important part of chronometer use, the methods used by officers to correct chronometers varied considerably, and were significantly determined by how much trust each officer placed in both the instrument being calibrated and the methods of calibration. Thirdly, each astronomer used different astronomical techniques on shore, and not all astronomical techniques were considered equal. This left room for negotiation, as Parry's deliberation on the longitude for the observatory at Winter Island in 1822 shows: if other authorities believed the correct longitude required adjustment, then this could be done by giving more weight to the outcome that most suited the required outcome. In sum: land-based observations were crucial to establishing longitude; these land-based observations were used to calibrate the chronometers but the methods used to do so varied considerably; and agreement could be achieved by giving some instruments or techniques more weight than others. The following sections further explore the implications of these points.

Deception Island: a truth-spot

The *Chanticleer* departed from Staten Island on 21 December 1828 and arrived at Deception Island on 29 December, another location selected for Foster's pendulum experiments. On arrival at Deception Island, where the *Chanticleer* was stationed for nearly two months, Foster determined the error of the chronometers on the Mean Time by transits of the Sun. This was a laborious procedure. Richard Owen explained the procedure in his 'Essay', stating that in fixed observatories the method 'will always be preferred' for rating chronometers, but admits that they did not apply this practice themselves and that portable transits were not much in use by navigators.[40] The method required 'very strict attention to preserve it in adjustment, but the adjustment itself requires more time than can generally be given to it' as it was 'a delicate and tedious operation; and not by any means so simple as is generally supposed'.[41]

[40] Owen, 'An Essay on the Management and Use of Chronometers', p. 13

[41] Ibid, p. 12

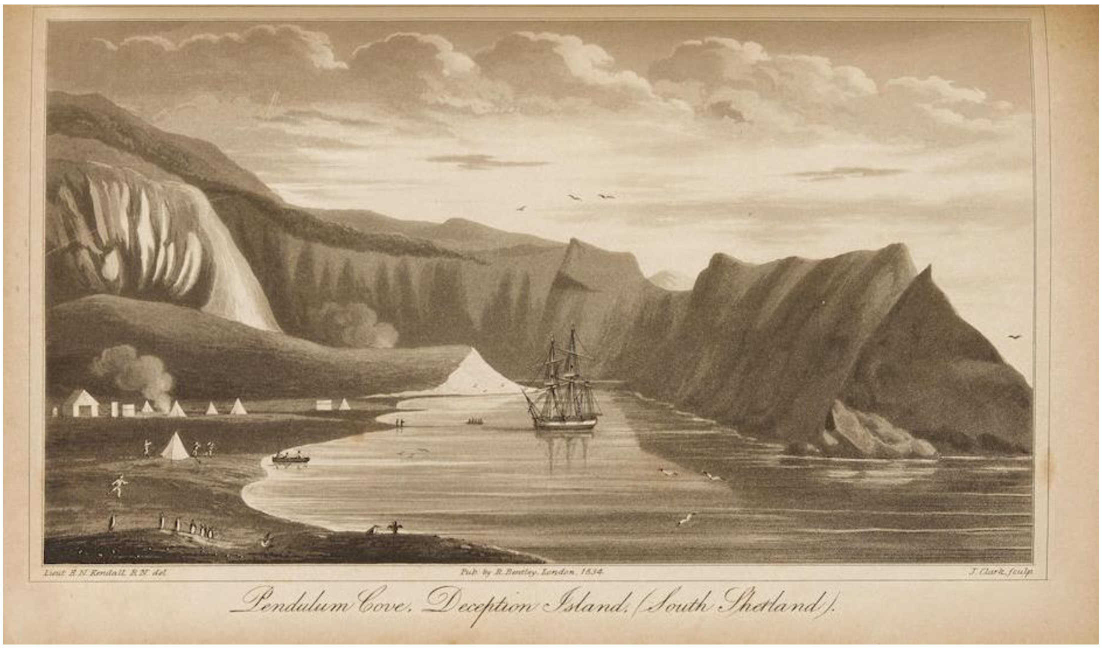


Figure 7.3: The *Chanticleer* at Pendulum Cove, Deception Island, 1828. W. H. B. Webster, *Narrative of a Voyage to the southern Atlantic Ocean in the Years 1828, 29, 30, Performed in H. M. Sloop* Chanticleer, *Volume I*, (London: Richard Bentley, 1834), p. 147

Richard Owen described three ways to set up the transit instrument: using the transit of certain stars; by the passage of the Sun; or by a circumpolar star. The adjustments determined in this way could take two to three days to 'perfect' or within 24 hours if all three were applied. Foster, 'a Hercules in astronomical and mechanical labor', as others described him, managed this tedious operation.[42] He spent several days setting up his transit telescope, which he 'enclosed in a light octagonal observatory designed for [its] use'.[43] He used Captain Kater's azimuth compass to set it to the meridian. Unfortunately, the weather did not allow Foster to use the transits of stars for adjusting the instrument and he had to depend upon transits of the Sun. For this, he had to rely on the chronometers despite the fact that his not knowing their exact rates would 'render the deductions therefore proportionally erroneous'.[44] The chronometer with the smallest rate of variance was selected by Foster to

[42] William Fitzwilliam Owen to Francis Beaufort, 1831, UKHO, MP58
[43] Astronomical Observations, HMS *Chanticleer*, Deception Island, 1829. UKHO, AO32: SFD7/7/1/6
[44] Ibid

time transits of the Sun's eastern and western limbs to determine the deviation. Foster does not specify which chronometer this was, but it is likely it was Murray 620, as this was used during all the subsequent observations of the Sun's transit.

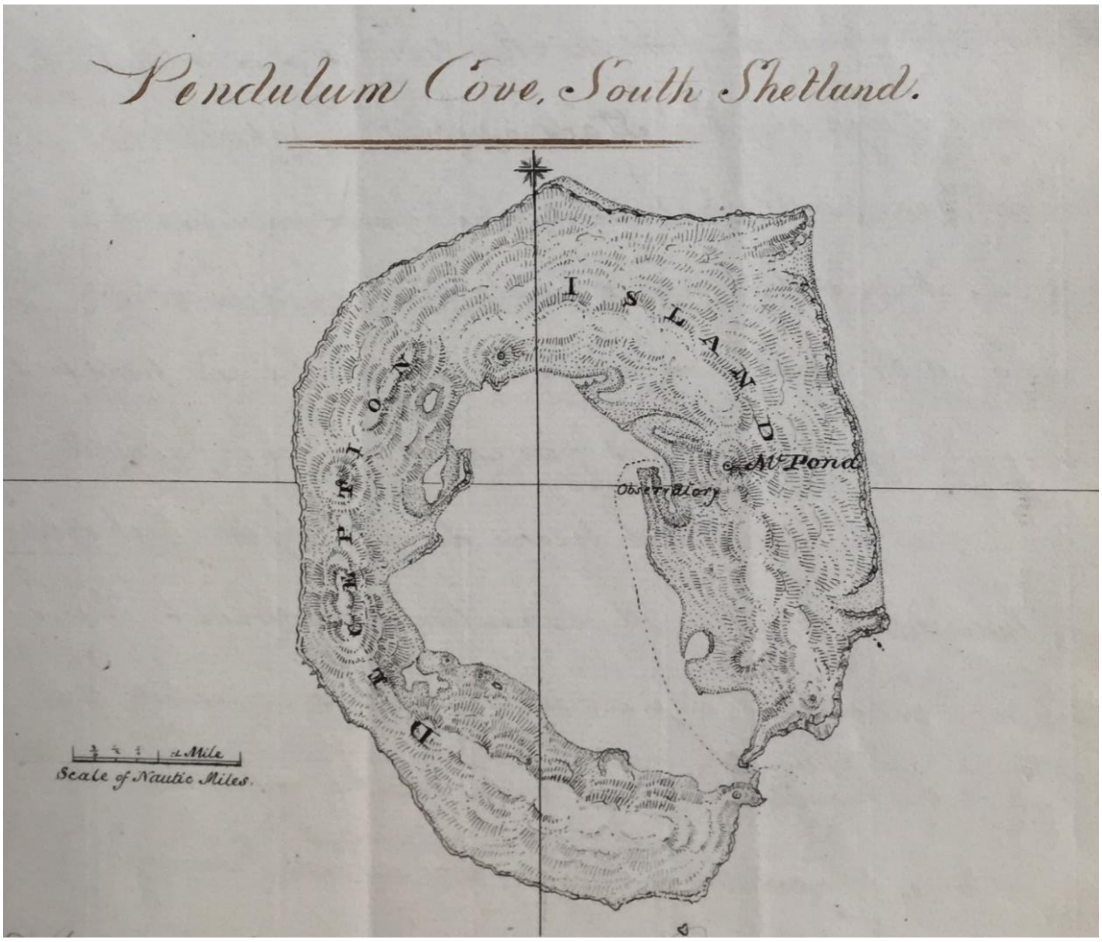


Figure 7.4: Foster's observatory on Deception Island, 1828. UKHO, AO32: SFD7/7/4.

The weather at Deception Island was poor, with clouds often obscuring the sky and thus also the observations. Foster wrote that 'indeed I never before in any Climate at any time witnessed such an … series of gales of wind & unfavourable W. for every kind of observation'.[45] Midshipman Henry Joseph Kay wrote in his journal that 'I really expect to see Captain, Mids, instruments and tents and all go flying over the adjacent hills some of these days, the squalls are so very strong and sudden'.[46] The weather lived up to his expectations,

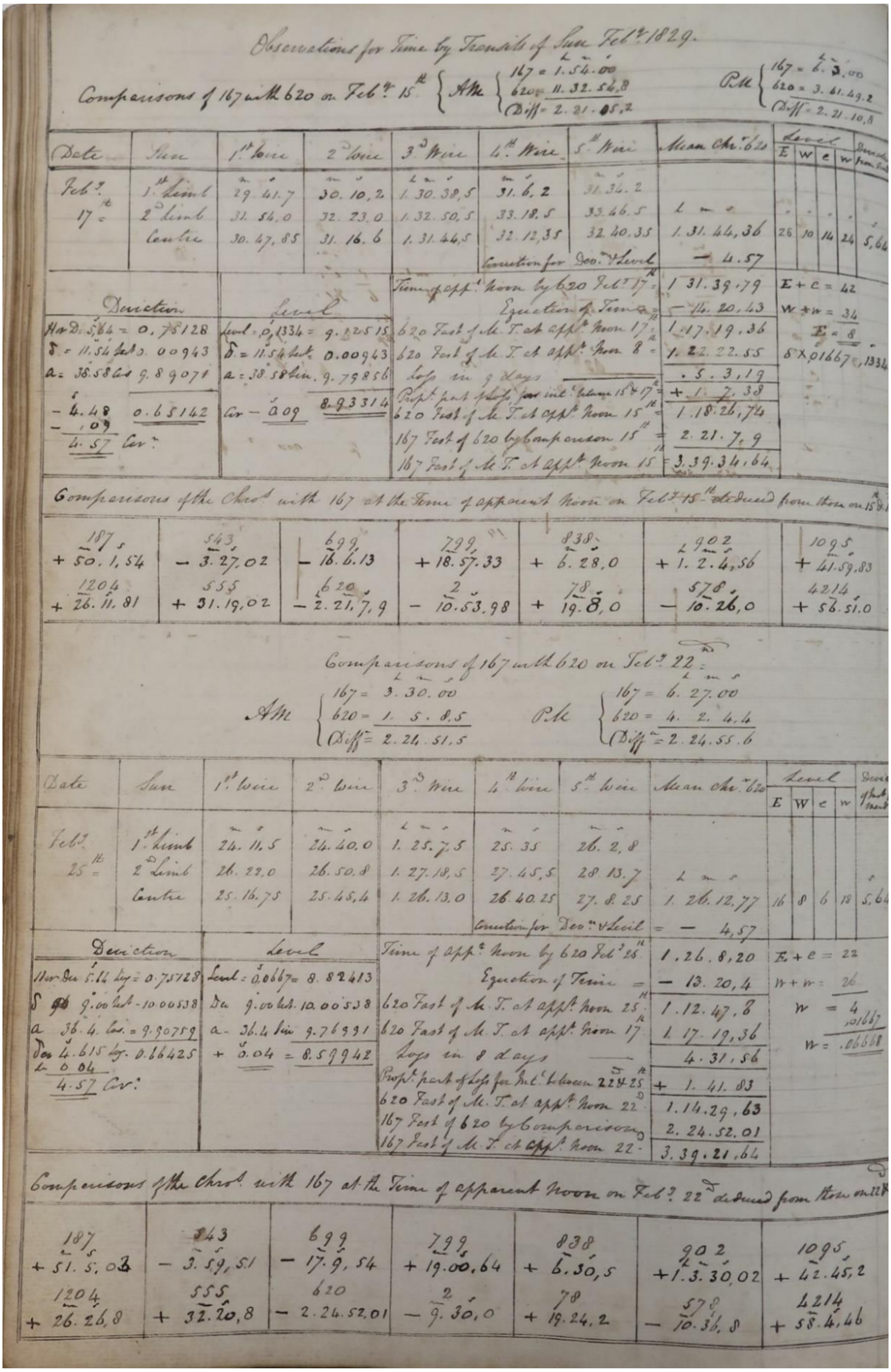
[45] Astronomical Observations, HMS *Chanticleer*, Deception Island, 1829. UKHO, AO32: SFD7/7/1/6
[46] Joseph Henry Kay, 'Journal kept by Midshipman Joseph Henry Kay During the Voyage of HMS *Chanticleer,* 1828-1831', in: *Four Travel Journals / The Americas, Antarctica and Africa / 1775-1874*, R.

as on 19 February ‘a squall took the Intensity Tent and as a Sailor said Dous’d it in a twinkling. I ran to save the Chrono^{r} and while doing that the same squall took all the others successively leaving none but our own and the Captain’s Marquees standing’.[47] Despite such difficulties, the crew obtained some of the necessary observations, and seven transits of the Sun across the meridian were observed, these being then used to determine the rates of the chronometers (figure 7.5).

Setting up and adjusting the transit instrument was only the first step in a long process. As with all astronomical determinations, substantial calculation was required. Foster’s first step was to compare Murray 620 with the standard McCabe 167. This was done in the morning and afternoon of 15 January. Although it was usual to compare the standard to the chronometer used for observing directly before and after observations, Foster did not follow this convention in this particular case, as the transit observations were taken on 17 January. Foster then observed the Sun’s first limb cross five wires of the transit telescope in short succession. Subsequently, the times of the Sun’s transit of its second limb across these wires were noted. These ten observations took just over four minutes and allowed Foster to determine the difference between the Sun’s first and second limb crossing the wires to get the time of the Sun’s centre of transit across each wire. The mean result of these transits was noted by Murray 620 (figure 7.6).

J. Campbell, Herbert K. Beals, Ann Savours, Anita McConnell, Roy Bridges, eds. (New York: Routledge, 2016), p. 309

[47] Ibid, p. 315


Observations for Time by Transits of Sun Feb.y 1829.

Comparisons of 167 with 620 on Feb.y 15th — AM: 167 = 1.54.00; 620 = 11.32.54,8; Diff = 2.21.05,2 — PM: 167 = 6.3.00; 620 = 3.41.49.2; Diff = 2.21.10,8

Date	Sun	1st Wire	2d Wire	3d Wire	4th Wire	5th Wire	Mean Chr. 620	Level E	W	e	w	Deviation from
Feb.y 17th	1st Limb	29.41.7	30.10,2	1.30.38,5	31.6.2	31.34.2						
	2d Limb	31.54,0	32.23.0	1.32.50,5	33.18.5	33.46.5						
	Centre	30.47,85	31.16.6	1.31.44,5	32.12,35	32.40.35	1.31.44,36	26	10	14	24	5,64
					Correction for Dev.n & Level		— 4.57					

Deviation	Level		
Hor D. 5,64 = 0.75128	Level = 0,1334 = 9.12515	Time of appt. Noon by 620 Feb.y 17th	1.31.39.79
δ = 11.54 lat 0.00943	δ = 11.54 lat. 0.00943	Equation of Time	— 14.20.43
a = 38.58 cos 9.89071	a = 38.58 sin. 9.79856	620 Fast of M.T. at appt. Noon 17th	1.17.19.36
— 4.48 0.65142	Cr — 0.09 8.93314	620 Fast of M.T. at appt. Noon 8th	1.22.22.55
— .09		Loss in 9 days	.5.3,19
4.57 Cor.		Propl. part of loss for int. between 15 & 17th	+ 1.7.38
		620 Fast of M.T. at appt. Noon 15th	1.18.26,74
		167 Fast of 620 by comparison 15th	2.21.7,9
		167 Fast of M.T. at appt. Noon 15	3.39.34,64

E + c = 42; W + w = 34; E = 8; 8 × 01667 = 1334

Comparisons of the Chrot. with 167 at the Time of apparent Noon on Feb.y 15th deduced from those on 15th

187 + 50.1,54	543 — 3.27.02	699 — 16.6.13	799 + 18.57.33	838 + 6.28,0	902 + 1.2.4,56	1095 + 41.59.83
1204 + 26.11.81	555 + 31.19,02	620 — 2.21.7,9	2 — 10.53.98	78 + 19.8,0	578 — 10.26,0	4214 + 56.51.0

Comparisons of 167 with 620 on Feb.y 22d — AM: 167 = 3.30.00; 620 = 1.5.8,5; Diff = 2.24.51,5 — PM: 167 = 6.27.00; 620 = 4.2.4.4; Diff = 2.24.55.6

Date	Sun	1st Wire	2d Wire	3d Wire	4th Wire	5th Wire	Mean Chr. 620	Level E	W	e	w	Deviation of transit
Feb.y 25th	1st Limb	24.11,5	24.40.0	1.25.7,5	25.35	26.2,8						
	2d Limb	26.22.0	26.50.8	1.27.18,5	27.45,5	28.13.7						
	Centre	25.16.75	25.45,4	1.26.13.0	26.40.25	27.8.25	1.26.12,77	16	8	6	18	5,64
					Correction for Dev.n & Level		= — 4,57					

Deviation	Level		
Hor Dev 5.64 log = 0.75728	Level = 0.0667 = 8.82413	Time of appt. Noon by 620 Feb.y 25th	1.26.8,20
δ 9.00 lat. 10.00538	Da 9.00 lat. 10.00538	Equation of Time	— 13.20,4
a 36.4 cos. = 9.90759	a — 36.4 sin 9.76991	620 Fast of M.T. at appt. Noon 25th	1.12.47.8
Dev 4.615 log. 0.66425	+ 0.04 = 8.59942	620 Fast of M.T. at appt. Noon 17th	1.17.19,36
+ 0.04		Loss in 8 days	4.31,56
4.57 Cor.		Propl. part of loss for Int. between 22 & 25th	+ 1.41.83
		620 Fast of M.T. at appt. Noon 22d	1.14.29,63
		167 Fast of 620 by Comparison	2.24.52.01
		167 Fast of M.T. at appt. Noon 22	3.39.21,64

E + e = 22; W + w = 26; w = 4; .01667; w = .06668

Comparisons of the Chrot. with 167 at the Time of apparent Noon on Feb.y 22d deduced from those on 22d

187 + 51.5,03	543 — 3.59,51	699 — 17.9,54	799 + 19.00,64	838 + 6.30,5	902 + 1.3.30,02	1095 + 42.45,2
1204 + 26.26,8	555 + 32.20,8	620 — 2.24.52.01	2 — 9.30,0	78 + 19.24.2	578 — 10.36,8	4214 + 58.4,46

Figure 7.5: Foster's observations of the Sun's transit on Deception Island, February 1829. UKHO, SFD9/12/2

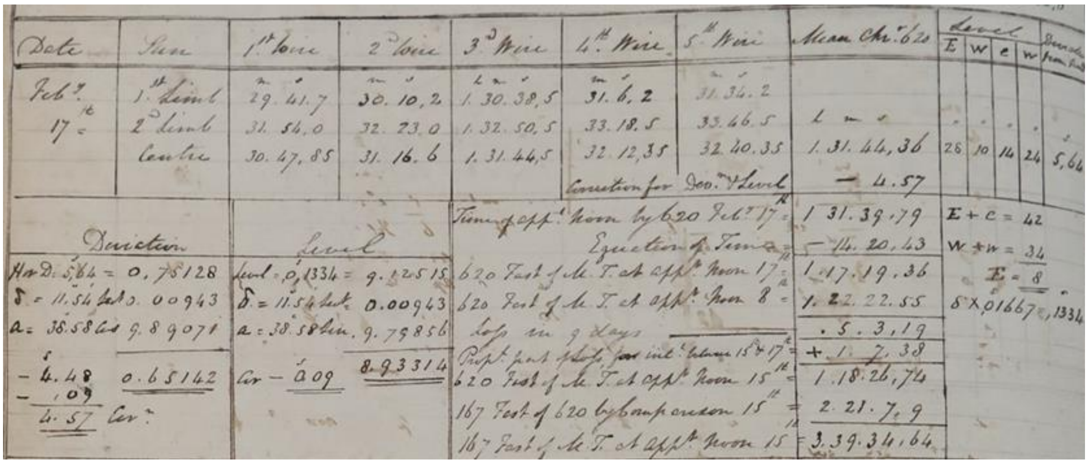


Figure 7.6: Foster's observation for the Sun's transit on Februray 12th 1829. UKHO, SFD9/12/2

The process was still far from complete. Although the transit instrument may have taken three or four days to set up correctly, it still required correction, as the time of the transit had to be corrected for deviation and level. As with all calculations, this involved taking the secant, co-secant and sine from the tables depending on the values determined by the compass and spirit level. The calculated correction was then subtracted from the Mean Time of the transit to give the time of apparent noon by Murray 620. Applying the Equation of Time gave the time of mean noon. Again, chronometer Murray 620 was compared to McCabe 167, and the difference between the two recalculated to determine the Mean Time of the Sun's transit by the standard (figure 7.7 and 7.8).

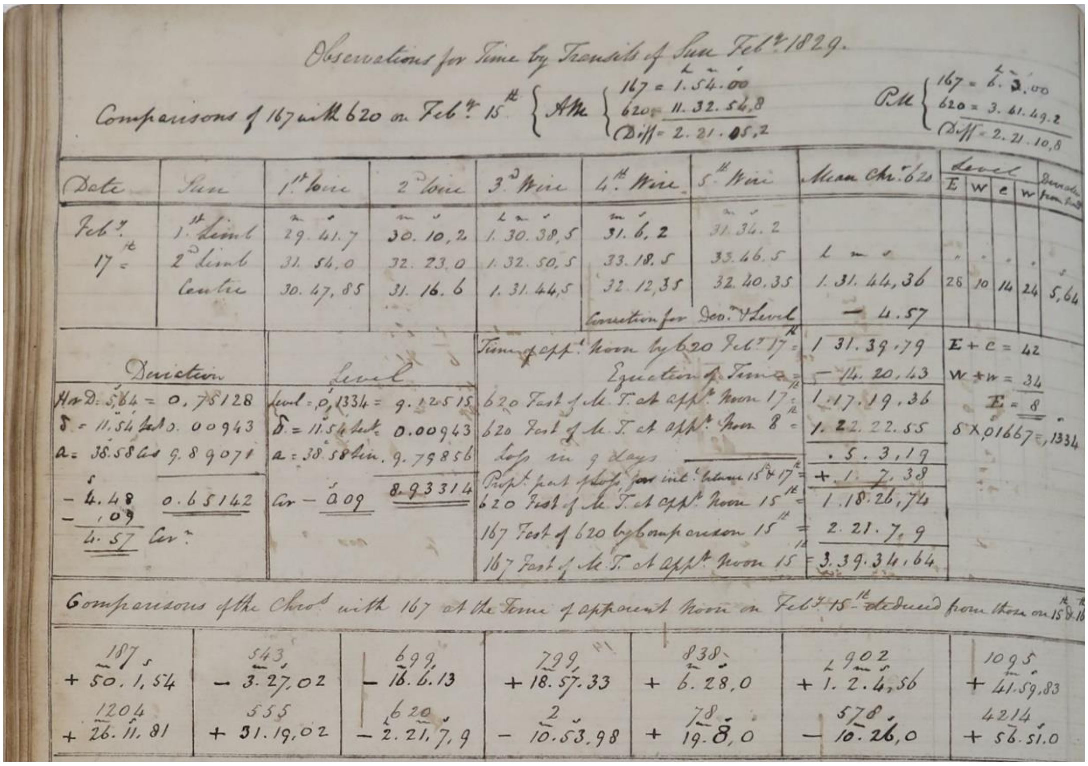
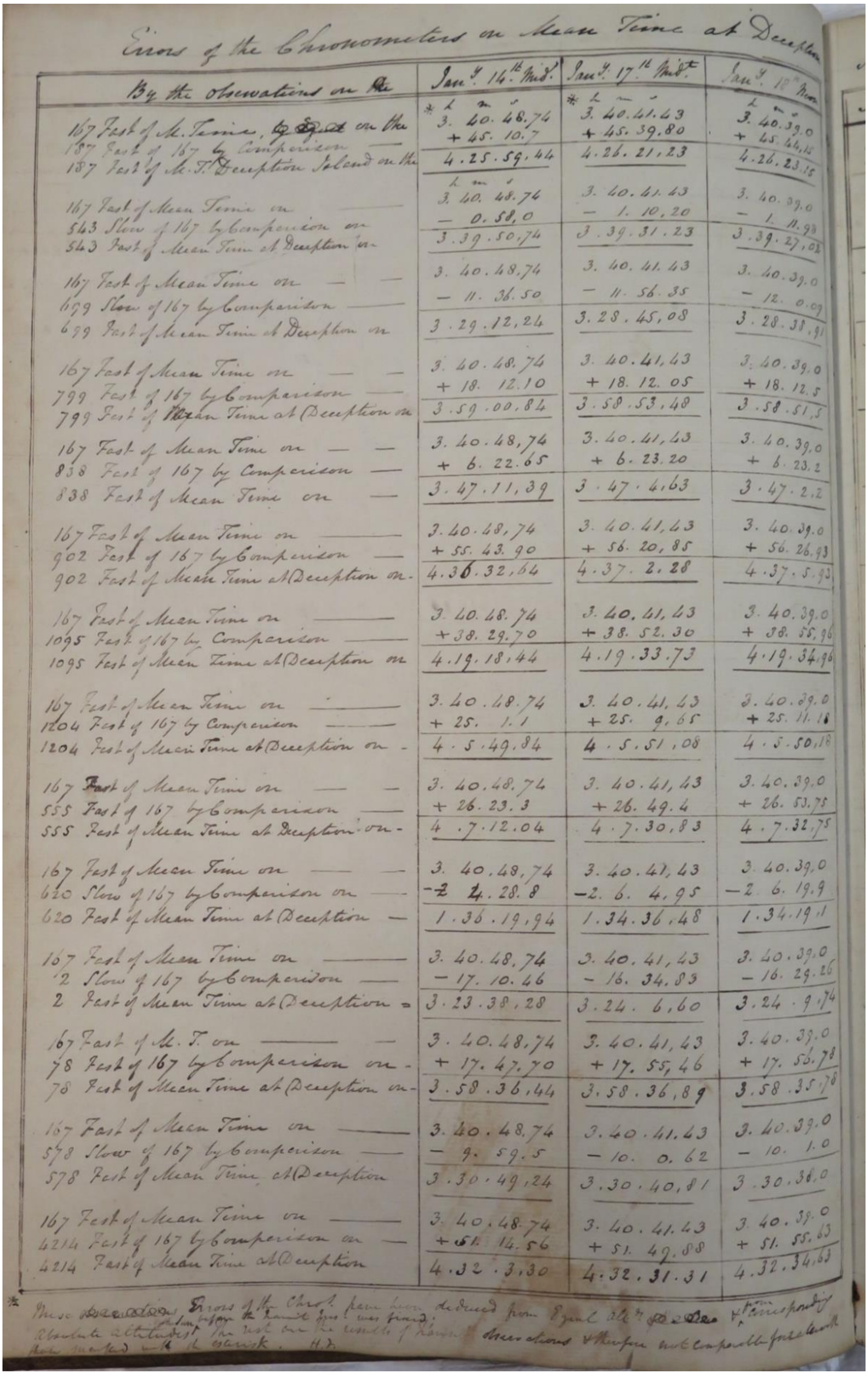


Figure 7.7: Corrections and calculations required to determine the time by the Sun's transit. UKHO, SFD9/12/2

Figure 7.8: Corrections and calculations required to determine the time by the Sun's transit. UKHO, SFD9/12/2

Using the error of the standard against the Mean Time at the place of observation, Foster then determined the error for each chronometer by comparison. Figures 7.9 and 7.10 show the error as calculated by Foster on January 14, 17, 18, 26 and on February 1, 8, 15, 22 and 28. Foster determined the error of the chronometers in the same manner once a week for the duration of their stay at Deception Island (figure 7.11). This enabled him to determine exact rates for the determination of the longitude.

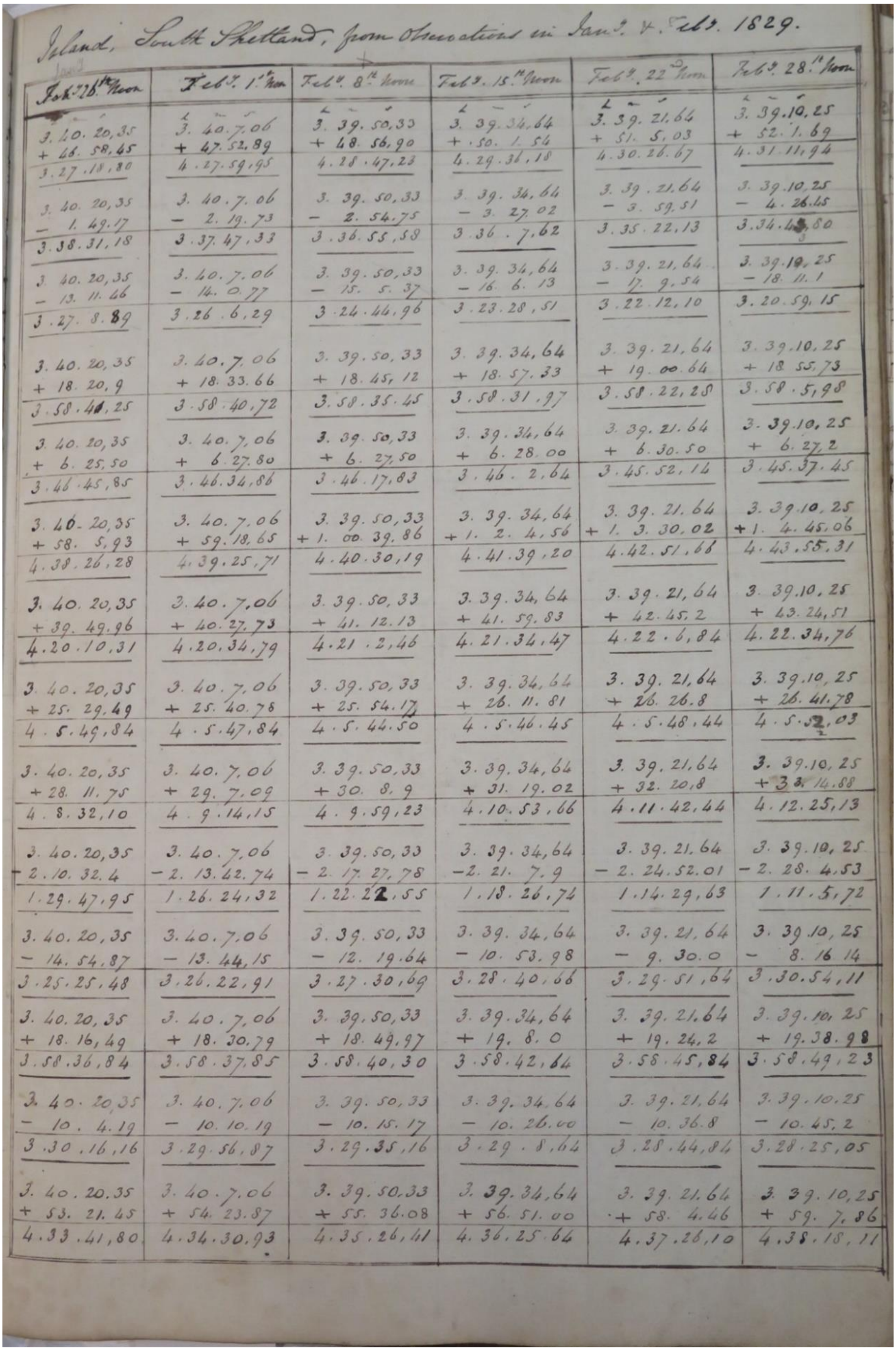


Errors of the Chronometers on Mean Time at Decep[tion]

By the observations on the	Jany. 14th Midt.	Jany. 17th Midt.	Jany. 18th M[idt.]
167 Fast of M. Time, by Equal on the	* h m s 3. 40. 48,74	* h m s 3. 40.41.43	h m s 3. 40.39.0
187 Fast of 167 by Comparison —	+ 45. 10.7	+ 45. 39.80	+ 45. 44,15
187 Fast of M.T. Deception Island on the	4.25.59.44	4.26.21,23	4.26.23.15
167 Fast of Mean Time on —	h m s 3. 40. 48.74	3. 40. 41. 43	3. 40. 39.0
543 Slow of 167 by Comparison on	— 0. 58,0	— 1. 10,20	— 1. 11.93
543 Fast of Mean Time at Deception on	3.39.50,74	3.39.31.23	3.39.27,07
167 Fast of Mean Time on — —	3. 40.48,74	3. 40. 41. 43	3. 40.39.0
699 Slow of 167 by Comparison —	— 11. 36.50	— 11. 56. 35	— 12. 0.09
699 Fast of Mean Time at Deception on	3.29.12,24	3.28.45,08	3.28.38,91
167 Fast of Mean Time on — —	3. 40. 48.74	3. 40.41,43	3. 40.39.0
799 Fast of 167 by Comparison —	+ 18. 12.10	+ 18. 12. 05	+ 18. 12.5
799 Fast of Mean Time at Deception on	3.59.00,84	3.58.53.48	3.58.51,5
167 Fast of Mean Time on — —	3. 40.48,74	3. 40.41,43	3. 40. 39.0
838 Fast of 167 by Comparison —	+ 6. 22.65	+ 6. 23.20	+ 6. 23.2
838 Fast of Mean Time on —	3.47.11,39	3.47.4,63	3.47.2,2
167 Fast of Mean Time on —	3.40.48,74	3. 40.41,43	3. 40.39.0
902 Fast of 167 by Comparison —	+ 55. 43.90	+ 56. 20,85	+ 56. 26,93
902 Fast of Mean Time at Deception on	4.36.32,64	4.37. 2.28	4.37.5,93
167 Fast of Mean Time on —	3. 40. 48. 74	3. 40. 41, 43	3. 40,39.0
1095 Fast of 167 by Comparison —	+ 38. 29.70	+ 38. 52. 30	+ 38. 55,96
1095 Fast of Mean Time at Deception on	4.19.18,44	4.19.33.73	4.19.34,96
167 Fast of Mean Time on —	3. 40.48.74	3. 40.41,43	3. 40.39.0
1204 Fast of 167 by Comparison —	+ 25. 1.1	+ 25. 9,65	+ 25. 11.16
1204 Fast of Mean Time at Deception on	4.5.49,84	4.5.51,08	4.5.50,16
167 Fast of Mean Time on — —	3. 40.48.74	3. 40.41,43	3. 40.39.0
555 Fast of 167 by Comparison	+ 26. 23.3	+ 26. 49.4	+ 26. 53.75
555 Fast of Mean Time at Deception on	4.7.12.04	4.7.30,83	4.7.32,75
167 Fast of Mean Time on —	3. 40,48,74	3. 40.41,43	3. 40.39,0
620 Slow of 167 by Comparison on —	-2 4.28.8	-2. 6. 4,95	-2. 6. 19.9
620 Fast of Mean Time at Deception —	1.36.19,94	1.34.36,48	1.34.19.1
167 Fast of Mean Time on —	3. 40.48,74	3. 40. 41,43	3. 40.39,0
2 Slow of 167 by Comparison —	— 17. 10.46	— 16. 34.83	— 16. 29.26
2 Fast of Mean Time at Deception	3.23.38,28	3.24. 6,60	3.24.9,74
167 Fast of M.T. on —	3. 40.48,74	3. 40.41,43	3. 40.39,0
78 Fast of 167 by Comparison on	+ 17. 47,70	+ 17. 55,46	+ 17. 56,78
78 Fast of Mean Time at Deception on	3.58.36,44	3.58.36,89	3.58.35,78
167 Fast of Mean Time on —	3. 40.48,74	3. 40.41.43	3. 40.39.0
578 Slow of 167 by Comparison —	— 9. 59.5	— 10. 0.62	— 10. 1.0
578 Fast of Mean Time at Deception	3.30.49,24	3.30.40,81	3.30.38.0
167 Fast of Mean Time on —	3. 40.48.74	3. 40. 41.43	3. 40. 39.0
4214 Fast of 167 by Comparison on —	+ 51. 14.56	+ 51. 49.88	+ 51. 55.63
4214 Fast of Mean Time at Deception	4.32.3,30	4.32.31.31	4.32.34,63

* These Errors of the Chrons. have been deduced from Equal altds. [illegible] & corresponding Absolute altitudes before the transit instrt. was fixed: the rest on the results of [illegible] observations & therefore not comparable [illegible] those marked with the asterisk. H.F.

Figure 7.9: Errors of the chronometers on Mean Time at Deception Island, January and February 1829. UKHO, SFD9/12/2



Island, South Shetland, from Observations in Jany. & Feby. 1829.

Feby. 26th Noon	Feby. 1st Noon	Feby. 8th Noon	Feby. 15th Noon	Feby. 22d Noon	Feby. 28th Noon
3.40.20,35	3.40.7.06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
+ 46.58,45	+ 47.52,89	+ 48.56,90	+ 50.1.54	+ 51.5,03	+ 52.1.69
3.27.18,80	4.27.59,95	4.28.47,23	4.29.36,18	4.30.26.67	4.31.11,94
3.40.20,35	3.40.7.06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
− 1.49.17	− 2.19.73	− 2.54.75	− 3.27.02	− 3.59.51	− 4.26.45
3.38.31,18	3.37.47,33	3.36.55,58	3.36.7.62	3.35.22,13	3.34.43,80
3.40.20,35	3.40.7.06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
− 13.11.46	− 14.0.77	− 15.5.37	− 16.6.13	− 17.9.54	− 18.11.1
3.27.8.89	3.26.6,29	3.24.44,96	3.23.28,51	3.22.12,10	3.20.59,15
3.40.20,35	3.40.7.06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
+ 18.20,9	+ 18.33.66	+ 18.45,12	+ 18.57.33	+ 19.00.64	+ 18.55.73
3.58.41,25	3.58.40,72	3.58.35.45	3.58.31,97	3.58.22,28	3.58.5,98
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34,64	3.39.21.64	3.39.10,25
+ 6.25,50	+ 6.27.80	+ 6.27,50	+ 6.28.00	+ 6.30.50	+ 6.27,2
3.46.45,85	3.46.34,86	3.46.17,83	3.46.2,64	3.45.52,14	3.45.37.45
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34,64	3.39.21.64	3.39.10,25
+ 58.5,93	+ 59.18,65	+ 1.00.39.86	+ 1.2.4,56	+ 1.3.30.02	+ 1.4.45.06
4.38.26,28	4.39.25,71	4.40.30,19	4.41.39,20	4.42.51,66	4.43.55.31
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
+ 39.49.96	+ 40.27.73	+ 41.12.13	+ 41.59.83	+ 42.45.2	+ 43.24,51
4.20.10,31	4.20.34,79	4.21.2,46	4.21.34,47	4.22.6,84	4.22.34,76
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
+ 25.29,49	+ 25.40.78	+ 25.54.17	+ 26.11.81	+ 26.26.8	+ 26.41.78
4.5.49,84	4.5.47,84	4.5.44.50	4.5.46.45	4.5.48,44	4.5.52,03
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
+ 28.11.75	+ 29.7.09	+ 30.8,9	+ 31.19.02	+ 32.20,8	+ 33.14.88
4.8.32,10	4.9.14,15	4.9.59,23	4.10.53,66	4.11.42,44	4.12.25,13
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34,64	3.39.21.64	3.39.10,25
− 2.10.32.4	− 2.13.42.74	− 2.17.27,78	− 2.21.7.9	− 2.24.52.01	− 2.28.4.53
1.29.47,95	1.26.24,32	1.22.22,55	1.18.26,74	1.14.29,63	1.11.5,72
3.40.20,35	3.40.7.06	3.39.50,33	3.39.34,64	3.39.21.64	3.39.10,25
− 14.54,87	− 13.44,15	− 12.19.64	− 10.53.98	− 9.30.0	− 8.16.14
3.25.25,48	3.26.22,91	3.27.30,69	3.28.40,66	3.29.51,64	3.30.54,11
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
+ 18.16,49	+ 18.30.79	+ 18.49.97	+ 19.8.0	+ 19.24,2	+ 19.38.98
3.58.36,84	3.58.37,85	3.58.40,30	3.58.42,64	3.58.45,84	3.58.49,23
3.40.20,35	3.40.7,06	3.39.50,33	3.39.34.64	3.39.21,64	3.39.10,25
− 10.4.19	− 10.10.19	− 10.15.17	− 10.26.00	− 10.36.8	− 10.45,2
3.30.16,16	3.29.56,87	3.29.35,16	3.29.8,64	3.28.44,84	3.28.25,05
3.40.20.35	3.40.7.06	3.39.50,33	3.39.34,64	3.39.21,64	3.39.10,25
+ 53.21.45	+ 54.23.87	+ 55.36.08	+ 56.51.00	+ 58.4.46	+ 59.7.86
4.33.41,80	4.34.30.93	4.35.26,41	4.36.25.64	4.37.26,10	4.38.18,11

Figure 7.10: Errors of the chronometers on Mean Time at Deception Island, January and February, 1829. UKHO, SFD9/12/2

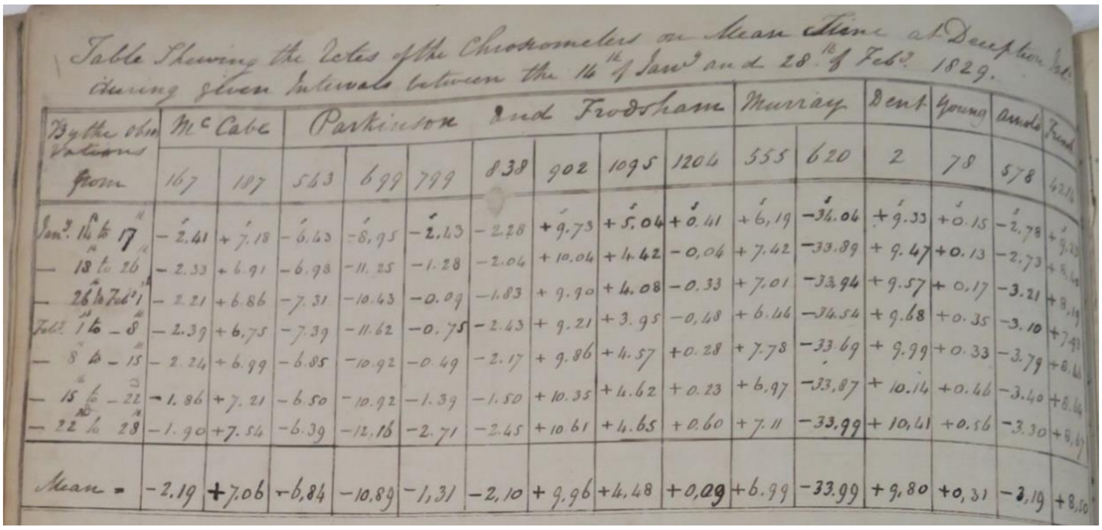


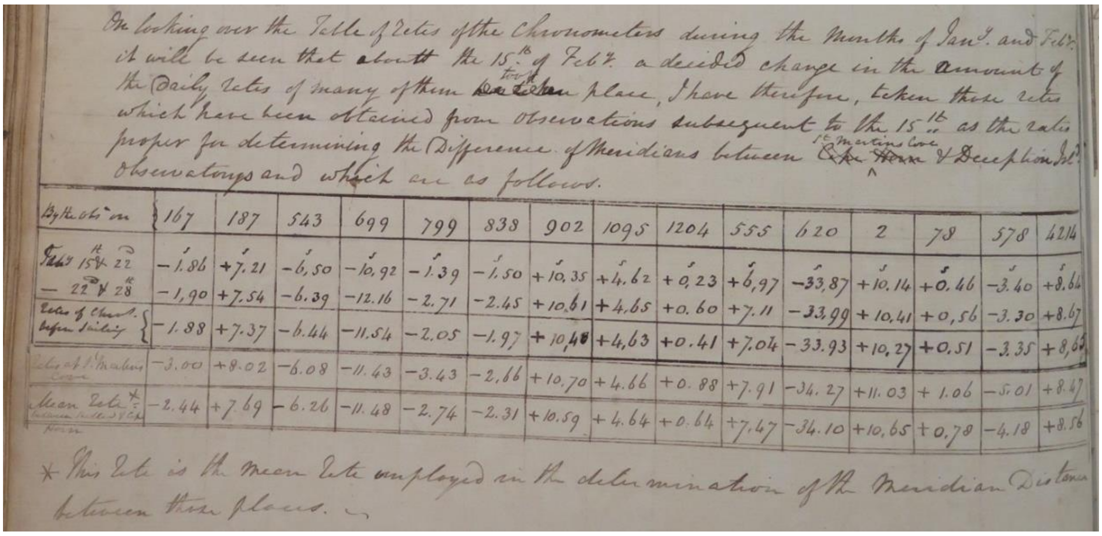
Table Shewing the Rates of the Chronometers on Mean Time at Deception Isl. during given Intervals between the 14th of Jany and 28th of Feby 1829.

By the observations from	McCabe		Parkinson and Frodsham							Murray		Dent	Young	Arnold	Frod
	167	187	563	699	799	838	902	1095	1204	555	620	2	78	578	[illegible]
Jany 14th to 17th	− 2.41	+ 7.18	− 6.43	− 8.95	− 2.43	− 2.28	+ 9.73	+ 5.04	+ 0.41	+ 6.19	− 34.06	+ 9.33	+ 0.15	− 2.78	[illegible]
— 18 to 26	− 2.33	+ 6.91	− 6.98	− 11.25	− 1.28	− 2.04	+ 10.04	+ 4.42	− 0.04	+ 7.42	− 33.89	+ 9.47	+ 0.13	− 2.73	[illegible]
— 26th to Feby 1	− 2.21	+ 6.86	− 7.31	− 10.43	− 0.09	− 1.83	+ 9.90	+ 4.08	− 0.33	+ 7.01	− 33.94	+ 9.57	+ 0.17	− 3.21	[illegible]
Feby 1st to 8	− 2.39	+ 6.75	− 7.39	− 11.62	− 0.75	− 2.43	+ 9.21	+ 3.95	− 0.48	+ 6.46	− 34.54	+ 9.68	+ 0.35	− 3.10	[illegible]
— 8 to 15	− 2.24	+ 6.99	− 6.85	− 10.92	− 0.49	− 2.17	+ 9.86	+ 4.57	+ 0.28	+ 7.78	− 33.69	+ 9.99	+ 0.33	− 3.79	[illegible]
— 15 to 22	− 1.86	+ 7.21	− 6.50	− 10.92	− 1.39	− 1.50	+ 10.35	+ 4.62	+ 0.23	+ 6.97	− 33.87	+ 10.14	+ 0.46	− 3.40	[illegible]
— 22 to 28	− 1.90	+ 7.54	− 6.39	− 12.16	− 2.71	− 2.45	+ 10.61	+ 4.65	+ 0.60	+ 7.11	− 33.99	+ 10.41	+ 0.56	− 3.30	[illegible]
Mean =	− 2.19	+ 7.06	− 6.84	− 10.89	− 1.31	− 2.10	+ 9.96	+ 4.48	+ 0.09	+ 6.99	− 33.99	+ 9.80	+ 0.31	− 3.19	[illegible]

Figure 7.11 Table of rates as determined by observation at Deception Island 1829. UKHO, SFD9/12/2

This should not be seen as an objective determination of mechanical precision corrected by astronomical accuracy: decisions were required when applying rates to the corrections for the chronometers. A rate had to be applied to the meridian distance between Staten Island and Deception Island. Foster chose to use the mean of the rates determined between 14 and 26 January and the mean rate determined on departure at Staten Island to correct the measurement of the meridian distance. For the departing rate, which would be taken into account for the next meridian distance, Foster chose only to take the rates in account determined after 15 February as 'about the 15th of Feby a decided change in the amount of the daily rates of many of them took place … for determining the difference of meridians between St. Martins Cove & Deception Island' (figure 7.12).[48]

[48] Astronomical Observation Book, HMS *Chanticleer,* 1828-1831. UKHO, SFD9/12/2



On looking over the Table of Rates of the Chronometers during the Months of Jany. and Feby. it will be seen that about the 15th of Feby. a decided change in the amount of the Daily rates of many of them took place, I have therefore, taken those rates which have been obtained from Observations subsequent to the 15th as the rates proper for determining the Difference of Meridians between St. Martins Cove ~~Cape Horn~~ & Deception Isd. Observatorys and which are as follows.

By the Chron.	167	187	543	699	799	838	902	1095	1204	555	620	2	78	578	4214
Feby. 15th & 22nd	s −1.86	s +7.21	s −6,50	s −10,92	s −1.39	s −1,50	s +10,35	s +4.62	s +0,23	s +6,97	s −33,87	s +10.14	s +0.46	s −3.40	s +8.64
— 22nd & 28th	−1,90	+7.54	−6.39	−12.16	−2.71	−2.45	+10.61	+4.65	+0.60	+7.11	−33.99	+10.41	+0,56	−3.30	+8.67
Rates of Chront. before Sailing	−1.88	+7.37	−6.44	−11.54	−2.05	−1.97	+10,48	+4,63	+0.41	+7.04	−33.93	+10,27	+0.51	−3.35	+8,65
Rates at St. Martins Cove	−3.00	+8.02	−6.08	−11.43	−3.43	−2,66	+10.70	+4.66	+0.88	+7.91	−34.27	+11.03	+1.06	−5.01	+8.47
Mean Rate*	−2.44	+7.69	−6.26	−11.48	−2.74	−2.31	+10.59	+4.64	+0.64	+7.47	−34.10	+10,65	+0,78	−4.18	+8.56

* This Rate is the mean Rate employed in the determination of the Meridian Distance between those places.

Figure 7.12: Foster’s selection of rates for the meridian distance between Deception island and St. Martin’s Cove. UKHO, SFD9/12/2

At his home in London, Tiarks later re-examined Foster’s data to correct these rates through mathematical intervention. A first step in the validation of Foster’s process was to compare how the determinations by him ‘agree amongst themselves’, when he had performed more than one run.[49] Tiarks looked at the two runs between Deception Island and St. Martin’s Cove, deciding that ‘the smallness of this difference proves that the results are most likely very accurate’, but adopted for the meridian distance the results of only one run, as the return voyage ‘was long and unfavourable’.[50] Users may not yet have found agreement on all matters relating to chronometry, but one aspect was accepted: chronometers were considered more reliable over shorter distances.

Land-based observations played a significant and often overlooked role in maritime chronometry, although these observations were often hampered by the local conditions in which they were made. Foster, thoroughly instructed in astronomical observations, improvised when instructions could not be followed. He was able to do so due to his

[49] John Lewis Tiarks, ‘Dr. Tiarks’s Report on Captain Foster’s Chronometrical Observations’, W. H. B. Webster, *Narrative of a Voyage to the southern Atlantic Ocean in the Years 1828, 29, 30, Performed in H. M. Sloop* Chanticleer, *Volume II*, (London: Richard Bentley, 1834), p. 230
[50] Tiarks, ‘Dr. Tiarks’s Report on Captain Foster’s Chronometrical Observations’, p. 230

connections and experience with Pond at the Royal Observatory and his naval experience under Hall, Sabine and Parry. Foster relied on the transit instrument rather than the combination of various astronomical observations such as he had made on Winter Island with Parry.

Sabine, Fisher and Foster all relied on shore observations to determine 'more accurately' what the error and rate of each chronometer was. The method employed by Foster, outlined above, was described by Owen as the best for rating chronometers but also very complicated. Foster, an experienced observer, was able to do this: he had the time, training and resources available. Even so, it was a complicated and challenging affair. This is but one example of the difficulties that individuals faced in establishing the longitude of the place on land and it illustrates why the time-ball system for rating chronometers was suggested and finally introduced in the 1830s. This would help naval officers rate their chronometers more readily. But even if an error and rate was established astronomically, or by the known longitude of a place, this did not mean that this value was settled. Chronometers were often rated on departure and on arrival. If the rates then varied, officers would have to choose which rate to apply: that determined on departure, on arrival, or the mean of the two. As I show in the next section, this left more than enough room for the different interpretations of chronometric results.

Getting instruments to agree

Foster used his tables to select which chronometers to use between each station. This meant that whilst a particular chronometer might not be included in an initial calculation, it may have been employed in a subsequent one. To understand how Foster negotiated his determinations we can look more closely at the tables showing the chronometer rates produced on board the *Chanticleer.* Figure 7.13 is a modern representation of a selection of

Foster's data taken from the chronometer comparisons which Foster termed 'Table II'. It does not show how he would have used his own tables, but it can help us visualise what the data shows. The data was taken from the second column of Table 2, which thus shows the daily change in rates for each chronometer.

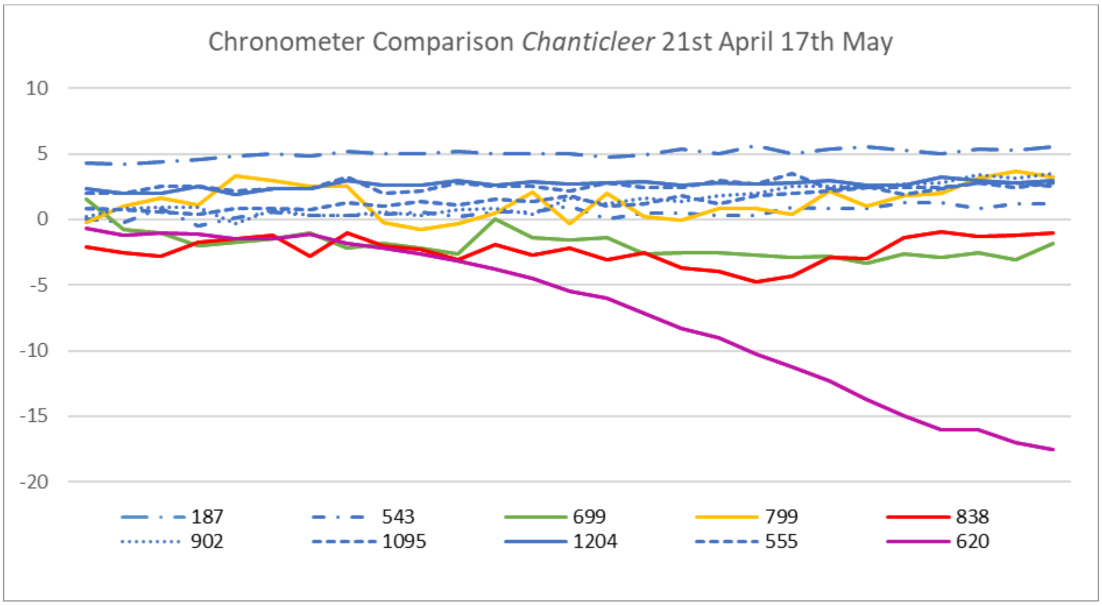


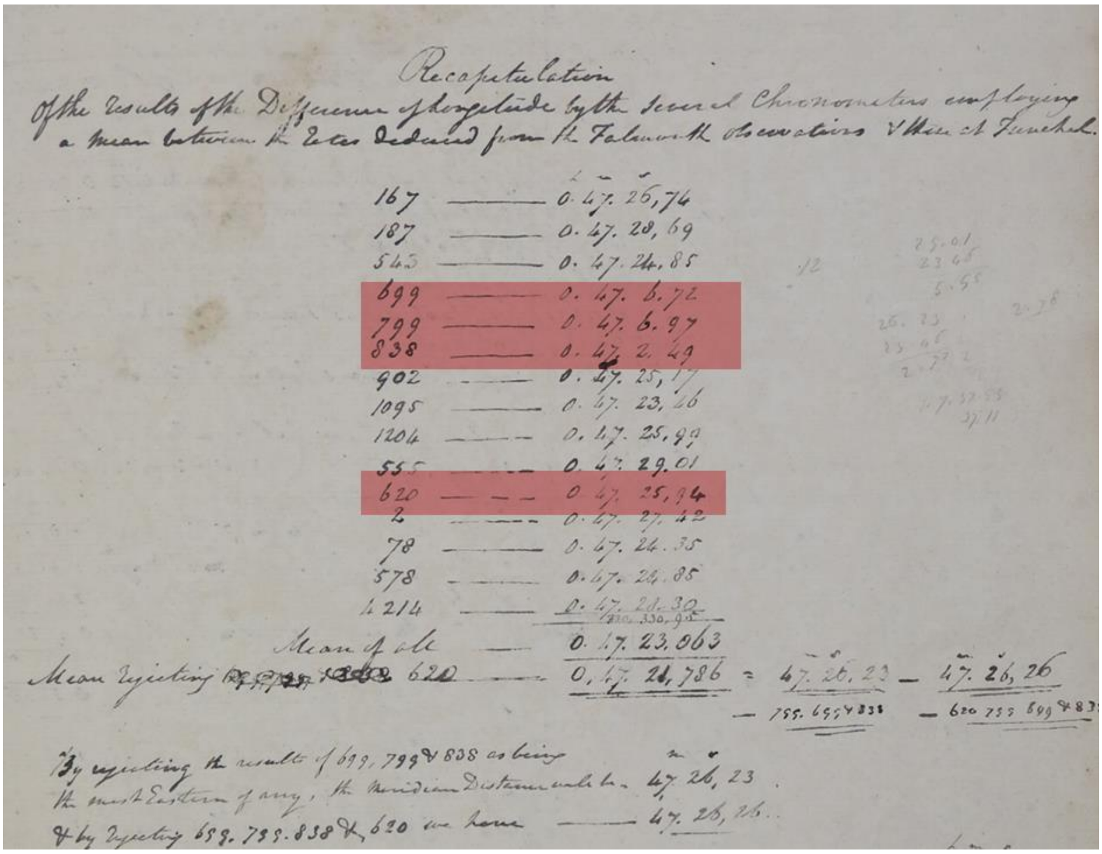
Figure 7.13: Showing the chronometer comparison on board HMS *Chanticleer* between 21 April and 17 May 1828. The x-axis shows the period of comparison, from 21 April to 17 May, 1828. The y-axis shows the rate of the chronometers in seconds fast or slow of the standard. UKHO, AO32: SFD7/7/1/7

The above example is based on the rates determined from 21 April to 17 May 1828. The lines in blue represent six of the eleven chronometers which Foster included in the measurement of the meridian distance. I have omitted the other five chronometers Foster included in this mean to give a clearer picture of the diverging chronometers. Chronometers P&F 699 (green), 799 (yellow), 838 (red) and Murray 620 (purple) were excluded due to the irregularity of their rates: 'chronometers 699, 799, 620 and 838 differ very considerably from each other, as well as from the mean result of all the rest'.[51] Foster concluded that employing P&F 699 and 799 on shore may have 'deranged' their rates.[52] For the other two, Foster

[51] Astronomical Observations, HMS *Chanticleer*, 1828-31. UKHO, AO32: SFD7/7/1/7
[52] Ibid

determined that ‘a very considerable change in the rates of both 620 and 838 [had] taken place during the passage from England to Madeira’.[53]

Foster’s rough observation book reveals more of his thinking. In his initial calculations, Foster compared the longitudes as determined by each chronometer using the mean of the rates determined at Falmouth and at Funchal (figure 7.14).



Recapitulation

Of the Results of the Difference of Longitude by the several Chronometers employing a Mean between the Rates Deduced from the Falmouth observations & those at Funchal.

167	0.47.26,74
187	0.47.28,69
543	0.47.24,85
699	0.47.6.72
799	0.47.6.97
838	0.47.2.49
902	0.47.25,17
1095	0.47.23,46
1204	0.47.25,99
555	0.47.29.01
620	0.47.25,94
2	0.47.27,42
78	0.47.24.35
578	0.47.24.85
L 214	0.47.24.30
Mean of all	0.47.23,063
Mean rejecting 620	0,47.21,786 = 47.26.23 — 47.26,26

By rejecting the results of 699, 799 & 838 as being the most Eastern of any, the Meridian Distance will be 47.26,23.
& by rejecting 699. 799. 838 & 620 we have — 47.26,26.

Figure 7.14: Longitudes for HMS *Chanticleer*, as calculated by the rates determined at Falmouth and Funchal. UKHO, SFD9/12/9

Foster calculated a mean longitude of these results in four different ways:

1. The longitude by the mean of all: 0.47.23,063
2. The longitude rejecting 620: 0.47.21,786
3. The longitude rejecting 799, 699 and 838: 0.47.26,23
4. The longitude rejecting 799, 699, 838 and 620: 0.47.26,26

[53] Astronomical Observations, HMS *Chanticleer*, 1828-31. UKHO, AO32: SFD7/7/1/7

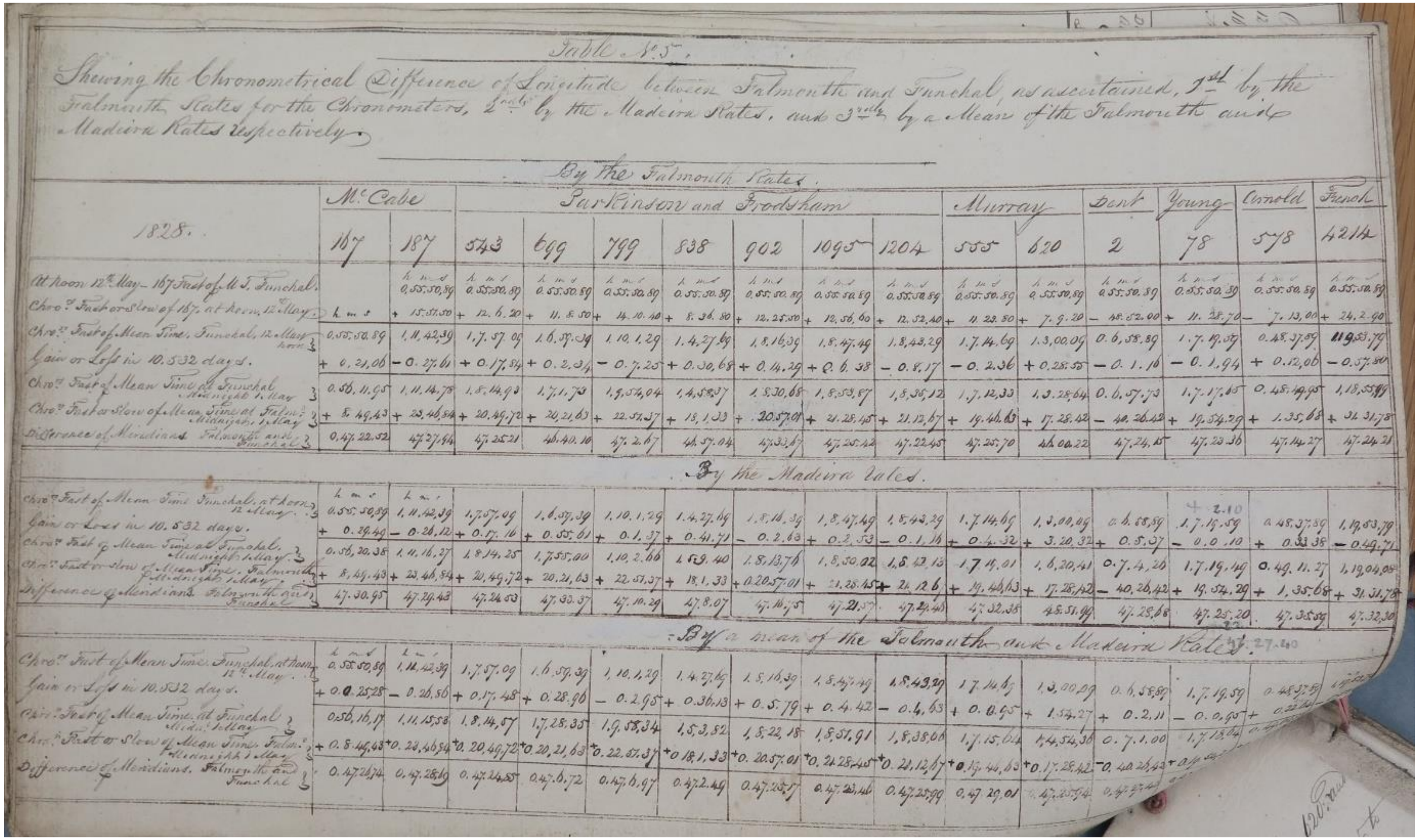


Table N. 5.

Shewing the Chronometrical Difference of Longitude between Falmouth and Funchal, as ascertained, 1st by the Falmouth Rates for the Chronometers, 2ndly by the Madeira Rates, and 3rdly by a Mean of the Falmouth and Madeira Rates respectively.

By the Falmouth Rates.

1828.	McCabe 167	McCabe 187	Parkinson and Frodsham 543	Parkinson and Frodsham 699	Parkinson and Frodsham 799	Parkinson and Frodsham 838	Parkinson and Frodsham 902	Parkinson and Frodsham 1095	Parkinson and Frodsham 1204	Murray 555	Murray 620	Dent 2	Young 78	Arnold 578	French 4214
At noon 12th May – 167 Fast of M. T. Funchal.		0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89	0.55.50.89
Chro. Fast or Slow of 167, at noon, 12 May.	h m s	+ 15.51.50	+ 12.6.20	+ 11.8.50	+ 14.10.40	+ 8.36.80	+ 12.25.50	+ 12.56.60	+ 12.52.40	+ 11.23.80	+ 7.9.20	− 48.52.00	+ 11.28.70	− 7.13.00	+ 24.2.90
Chro. Fast of Mean Time, Funchal, 12 May noon	0.55.50.89	1.11.42.39	1.7.57.09	1.6.57.39	1.10.1.29	1.4.27.69	1.8.16.39	1.8.47.49	1.8.43.29	1.7.14.69	1.3.00.09	0.6.58.89	1.7.19.59	0.48.37.59	1.19.53.79
Gain or Loss in 10.532 days.	+ 0.21.06	− 0.27.61	+ 0.17.54	+ 0.2.34	− 0.7.25	+ 0.30.68	+ 0.14.29	+ 0.6.38	− 0.8.17	− 0.2.36	+ 0.28.55	− 0.1.16	− 0.1.94	+ 0.12.06	− 0.57.80
Chro. Fast of Mean Time at Funchal Midnight 1 May	0.56.11.95	1.11.14.78	1.8.14.93	1.7.1.73	1.9.54.04	1.4.58.37	1.8.30.68	1.8.53.87	1.8.35.12	1.7.12.33	1.3.28.64	0.6.57.73	1.7.17.65	0.48.49.95	1.18.55.99
Chro. Fast or Slow of Mean Time at Falm. Midnight 1 May	+ 8.49.43	+ 23.46.84	+ 20.49.72	+ 20.21.63	+ 22.51.37	+ 18.1.33	+ 20.57.01	+ 21.28.45	+ 21.12.67	+ 19.46.63	+ 17.28.42	− 40.26.42	+ 19.54.29	+ 1.35.68	+ 31.31.78
Difference of Meridians Falmouth and Funchal	0.47.22.52	47.27.44	47.25.21	46.40.16	47.2.67	46.57.04	47.33.67	47.25.42	47.22.45	47.25.70	46.00.22	47.24.15	47.23.36	47.14.27	47.24.21

By the Madeira Rates.

	167	187	543	699	799	838	902	1095	1204	555	620	2	78	578	4214
Chro. Fast of Mean Time Funchal, at noon 12 May.	0.55.50.89	1.11.42.39	1.7.57.09	1.6.57.39	1.10.1.29	1.4.27.69	1.8.16.39	1.8.47.49	1.8.43.29	1.7.14.69	1.3.00.09	0.6.58.89	+ 2.10 1.7.19.59	0.48.37.89	1.19.53.79
Gain or Loss in 10.532 days.	+ 0.29.49	− 0.26.12	+ 0.17.16	+ 0.55.61	+ 0.1.37	+ 0.41.71	− 0.2.63	+ 0.2.53	− 0.1.16	+ 0.4.32	+ 3.20.32	+ 0.5.07	− 0.0.10	+ 0.33.38	− 0.49.71
Chro. Fast of Mean Time at Funchal. Midnight 1 May.	0.56.20.38	1.11.16.27	1.8.14.25	1.7.55.00	1.10.2.66	1.5.9.40	1.8.13.76	1.8.50.02	1.8.42.13	1.7.19.01	1.6.20.41	0.7.4.26	1.7.19.49	0.49.11.27	1.19.04.08
Chro. Fast or Slow of Mean Time, Falmouth Midnight 1 May	+ 8.49.43	+ 23.46.84	+ 20.49.72	+ 20.21.63	+ 22.51.37	+ 18.1.33	+ 0.20.57.01	+ 21.28.45	+ 21.12.6	+ 19.46.63	+ 17.28.42	− 40.26.42	+ 19.54.29	+ 1.35.68	+ 31.31.78
Difference of Meridians Falmouth and Funchal	47.30.95	47.29.43	47.24.53	47.33.37	47.10.29	47.8.07	47.16.75	47.21.57	47.29.48	47.32.38	48.51.99	47.28.68	47.25.20	47.35.59	47.32.30

By a mean of the Falmouth and Madeira Rates. 27.40

	167	187	543	699	799	838	902	1095	1204	555	620	2	78	578	4214
Chro. Fast of Mean Time Funchal, at noon 12th May.	0.55.50.89	1.11.42.39	1.7.57.09	1.6.57.39	1.10.1.29	1.4.27.69	1.8.16.39	1.8.47.49	1.8.43.29	1.7.14.69	1.3.00.09	0.6.58.89	1.7.19.59	0.48.37.59	[illegible]
Gain or Loss in 10.532 days.	+ 0.0.25.28	− 0.26.86	+ 0.17.48	+ 0.28.96	− 0.2.95	+ 0.36.13	+ 0.5.79	+ 0.4.42	− 0.4.63	+ 0.0.95	+ 1.54.27	+ 0.2.11	− 0.0.05	+ [illegible]	[illegible]
Chro. Fast of Mean Time at Funchal Midnt. 1 May	0.56.16.17	1.11.15.58	1.8.14.57	1.7.28.35	1.9.58.34	1.5.3.82	1.8.22.18	1.8.51.91	1.8.38.06	1.7.15.64	1.4.54.36	0.7.1.00	1.7.18.64	[illegible]	[illegible]
Chro. Fast or Slow of Mean Time Falm. Midnight 1 May	+ 0.8.46.43	+ 0.23.46.84	+ 0.20.49.72	+ 0.20.21.63	+ 0.22.51.37	+ 0.18.1.33	+ 0.20.57.01	+ 0.21.28.45	+ 0.21.12.67	+ 0.19.46.63	+ 0.17.28.42	− 0.40.26.42	+ [illegible]	[illegible]	[illegible]
Difference of Meridians, Falmouth and Funchal	0.47.26.74	0.47.28.19	0.47.24.85	0.47.6.72	0.47.6.97	0.47.2.49	0.47.25.57	0.47.23.46	0.47.25.99	0.47.29.01	0.47.25.94	0.47.27.4[illegible]	[illegible]	[illegible]	[illegible]

Figure 7.15: 'Table N. 5: Shewing the Chronometrical Difference of Longitude between Falmouth and Funchal, as ascertained, 1st by the Falmouth Rates for the Chronometers, 2ndly by the Madeira Rates, and 3rdly by a mean of the Falmouth and Madeira Rates respectively'. UKHO, AO32: SFD7/7/1/7

It is clear why Foster rejected 799, 699 and 838 from the mean as they clearly differ from the mean of the chronometers in the summary (figure 7.14). Removing them from the mean resulted in a more westerly determination. Foster's reason for rejecting Murray 620 was different. As mentioned above, Foster calculated three different longitudes for each chronometer; one using the Falmouth rates; one using the Funchal rates; and one based on the mean of these two rates (figure 7.15). It was the comparison between these three results for Murray 620 that led Foster to reject it.

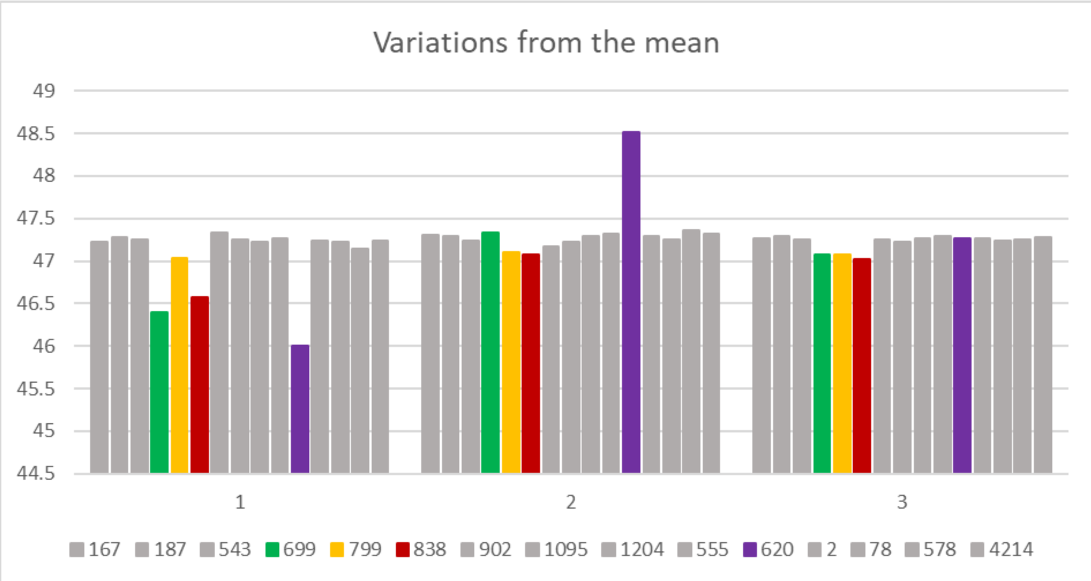


Figure 7.16: Values from figure 7.15 presented in graph form. This shows the longitude (x-axis) as computed by each of the chronometers depending on how the rates were calculated.

Figure 7.16 shows this analysis in graphical form. This shows the data taken from 'Table 5 part II' in which Foster abstracted the longitude results using different rates. The y-axis shows the resulting longitude. The chronometers which Foster selected for the longitude are shown in grey (in order that the rejected chronometers stand out more clearly). Section 1 shows the longitude using the Falmouth rates; section 2 the Madeira rates; section 3 the mean of both. Murray 620 fluctuated significantly in these three calculations, and in section 1, it is also clear that P&F 699, 838 and 799 would bring the average longitude down, placing

Funchal slightly more to the east. As section 3 shows, the mean of Murray 620 sat very closely to the results of the mean of the other chronometers.

We come back to the hierarchies of chronometers here. In this case, as Foster pointed out, pocket chronometers P&F 699 and 799 were the watches used to take observations on deck. As such, their results were generally somewhat suspect. The chronometer with the steadiest and smallest rate, considered the best chronometer, was employed as the standard (McCabe 167). This was then compared to the watches P&F 699 and 799 and the rest of the chronometers kept in the cabin. All the other chronometers were trusted to average out instrumental errors and to provide a check upon one another. Chronometers that were used on deck or on shore to time the observations were not necessarily excluded from this average, as this decision depended on their performance. In the above example, Foster found them inadequate, and attributed this to their use on shore. This was not always the case. In other determinations they were included: on-shore use did not necessarily rule out their inclusion in the mean, but they would often remain suspect and were excluded by Foster for the majority of meridian distances. Each decision was made on the spot and varied for each run. Sometimes the negotiation was simple: if a chronometer deviated too far from the mean it was excluded. But other considerations were also involved. During the passage between Staten Island and Montevideo for example, the chronometers were 'subjected to a change of Temp. amounting to 26^{o} of Fah^{t} scale viz between 69^{o} & 43^{o} … [and] to considerable motion during the heavy and constant gales of wind'.[54] Despite this, only two chronometers gave results that deviated far from the mean. These were the pocket chronometers P&F 699 and 799. P&F 699 was included despite having been 'worn in the Pocket as a common watch by Lieu^{t} Kendall', during a survey made prior to departure. Foster's reasoning was that by only applying the rate calculated on arrival at Montevideo, the result could 'be fairly taken along

[54] Astronomical Observation Book, Capt. Foster, 1828-31, HMS *Chanticleer.* UKHO, SFD9/12/2

with the other Chro^{s}’.[55] P&F 799 was excluded despite its result being ‘by no means very wide from the mean of all the rest’ on the basis that ‘it was always used as a journeyman, both at sea & in obtaining the necessary observations on shore at the different places visited’.[56] In this case, Foster relied on its use rather than its performance to determine that it should not be included in the mean.

It is clear that there was no golden rule for officers to follow when selecting chronometers to measure a meridian distance. In another instance, Foster applied a different approach. At a later stage of the voyage, Murray 620, previously excluded, started to work properly and so was included in the mean of the results. In the determination between Rio de Janeiro and Santa Cruz (using the rates determined at Rio de Janeiro), chronometers Arnold 578, Murray 555, P&F 699, 799 and 838 differed ‘widely’ from the others, a fact which led Foster to ‘question their accuracy’. Rather than reject them entirely, Foster ‘considered it right to reject them separately from having an equal value with the rest, and have only regarded their mean results as equivalent to one chronometer’.[57] Although, on average, it would be possible to select certain chronometers that in general performed better than others, these examples show that the average reliability of a chronometer did not guide its selection in all instances. In the runs between Funchal and Tenerife, between Funchal and San Antonio and between Funchal and the Panedo de San Pedro, the rates of the chronometers fluctuated too much for Foster to use the mean of the rates, or just those determined at either station. The rates had been determined at Funchal and thirty-six days later at Fernando Noronha. In between which the *Chanticleer* had stopped at the stations above. Foster only took sights to determine the local time at these stations. He did not stop to determine new rates. Because the rates determined at Fernando Noronha, differed

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[55] Astronomical Observation Book, Capt. Foster, 1828-31, HMS *Chanticleer.* UKHO, SFD9/12/2
[56] Ibid
[57] Ibid

considerably from those at Funchal, Foster determined the longitude of these places using a selection of the best chronometers which were then ‘corrected for irregularity of rate’.[58] To correct for this irregularity of rate, Foster applied interpolation, using the more complex equation shown in chapter 6, page 235. Even when the best instruments were employed in the safe hands of an experienced observer, how rates were determined and applied could vary considerably.

[58] Astronomical Observations, HMS *Chanticleer*, 1828-31. UKHO, AO32: SFD7/7/1/7

To verify these singular determinations, Foster also turned to other sources. Captain King had determined the longitude of Funchal in 1826 as 1h7m35,18s west of the Breakwater at Plymouth. This location, by correcting for the difference of longitude with Greenwich, could be used in comparison with Foster's results. Figure 7.17 is a transcription of Foster's deliberation for the longitude of Funchal, Madeira.

	Longitude of Funchal, Madeira	
1	By rejecting the results of 699, 799 & 838 as being the most Eastern of any, the meridian distance will be	0.47.26,23
2	& by rejecting 699, 799, 838 & 620 we have	0.47.26,26
3	The longitude of Funchal determined by Capt^{n} King in 1826 from the Breakwater at Plymouth 0.16.32,19[59] is	1.07.35,18
4	The Long^{d} of Funchal determined by myself from Falmouth the Flagstaff on Pendennis Castle being in 20.10,85[60] by the mean of 15 Chro^{s} four of which did not go very regularly is	1.07.33,913
5	If the four irregular going Chro^{s} be rejected, the Long^{d} of Madeira by the remaining 11 which agreed very nearly with each other is	1.07.37,11
6	The mean of these determinations may, it is presumed be put in competition with D^{r} Tiarks determinations,	1.07.35,40
7	the Long^{d} by D^{r} Tiarks	1.07.39,08
8	The Mean of all which is considered a nearer approximation to the truth then 1.7.39,08 the results of D^{r} Tiarks mean	1.07.37,24
9	From which if we deduct the long^{d} of Falmouth according to D^{r} Tiarks	0.20.10,85
10	We have for the Meridian Distance between Falmouth & Funchal	0.47.26.39
11	Which accords very nearly with the best results of the chronometers supplied to the Chanticleer – viz –	0.47.26,26
12	I shall therefore consider the long^{d} of Madeira as 1.7.37,24 West of Greenwich	

Figure 7.17: Foster's deliberation for the longitude of Funchal, transcribed from Foster's Astronomical Observation Book. UKHO, SFD9/12/2.

In steps 1 and 2 (indicated in the left-hand column) Foster calculated two possible meridian distances between Falmouth and Madeira by excluding the results of three

[59] Foster added this correction to King's longitude at Plymouth to get the meridian distance between Greenwich and Falmouth.

[60] This correction is the longitude of Falmouth as determined by Tiarks. Foster added this to get comparative data for all the longitudes from Greenwich.

chronometers (in step 1) and four chronometers (in step 2). Foster then proceeded to compare these determinations with those made by others in the same spot (the observations 'were taken on the very spot selected by Tiarks'): one by Captain King (in 1826) and the other by Tiarks (in 1822).[61] Foster took the mean of three determinations: firstly, that by King (step 3); secondly, by his own determination using all fifteen chronometers (step 4); and finally, the result by rejecting four chronometers (step 5). This mean result (step 6) was then compared to Tiarks' determination (step 7), which placed Funchal further west. The longitude according to Foster should be the mean of his calculated longitude and the determination by Tiarks: 1°07'37"24 (step 8). By deducting the longitude of Falmouth (step 9 – the longitude according to Tiarks), Foster calculated the meridian distance between Falmouth and Funchal (step 10). He concluded that this 'accords very nearly with the best results of the chronometers supplied to the Chanticleer'. This led him to:

> suggest the above alteration in the hitherto received longitude of Madeira. The almost exact coincidence of Capt. King's determination with my own and the circumstance of the meridian distance between Falmouth & Funchal measured by 11 chronometers in an interval of 10.5 days, being all in defect of Dr. Tiarks final result, whether deduced from the rates furnished by the Falmouth observations or the rates ascertained at Madeira, or from the mean of the rates at both those places, are of themselves sufficient, in my opinion to warrant a preference to the mean of these results of these observers being considered as the longitude of Madeira.[62]

Foster relied on the number of good instruments, the relative shortness of the interval and the agreement with King's determination to verify his account.

Tiarks again used his personal judgement when selecting which rates to apply to a meridian distance. He 'endeavoured to find the most probable results for the meridian distances chronometrically determined during the expedition'.[63] According to Tiarks, the 'near agreement of Captain Foster's equal altitudes shows his great skill in observations of

[61] Astronomical Observations, HMS *Chanticleer*, 1828-31. UKHO, AO32: SFD7/7/1/7
[62] Astronomical Observations, HMS *Chanticleer*, 1828-31. UKHO, AO32: SFD7/7/1/8
[63] Tiarks, 'Dr. Tiarks's Report on Captain Foster's Chronometrical Observations', p. 225

this kind, and the advanced state and correctness of the calculations afford unequivocal proof of his indefatigable industry'. Tiarks did not doubt the reliability of the instruments, 'as all were considered very excellent ones', but rather questioned Foster's method of storing them during the voyage.[64] Due to the alteration of their rates over very short intervals, Tiarks was 'inclined to believe that Captain Owen is right in finding fault with the manner in which the chronometers were suspended from the deck of the Chanticleer'. He added that his own experience confirmed that 'suspension from the upper deck of a vessel is not favourable to the going of timepieces'.[65] He corrected Foster's longitude for Madeira, using the rates Foster had determined at Funchal without including the Falmouth ones. Tiarks thought the run had been too long and that the rates had altered after the ship's departure.[66]

During the voyage of the *Beagle,* Fitzroy, Stokes and Stebbing were in charge of the twenty-two chronometers kept in Fitzroy's cabin. Stebbing, Fitzroy's personal assistant in charge of winding and comparison, was not charged with processing the data from the chronometers. This duty was the responsibility of the officers on the voyage: Fitzroy, Stokes, Lieutenant Bartholomew Sullivan and Alexander Usborne (the Master's assistant). Sullivan's and Usborne's chronometer duties appear to have been confined to the surveys performed in the schooner *Constitucion* on the coast of Peru. Only a few of the 'backstage' calculations involved in Fitzroy's chain of meridian distances have survived. All that remains for examination are the comparison and rate books, the published appendix and a notebook kept by John Lort Stokes, Mate and Assistant Surveyor on the *Beagle*. This was not a navigational notebook such as kept by Sabine, Fisher, and Foster. Rather, it contains general notes relating to more than one voyage in which there are a few sections that record Stokes' work on the chronometers. The notes relating to the chronometric procedures of the

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[64] Tiarks, 'Dr. Tiarks's Report on Captain Foster's Chronometrical Observations', p. 225
[65] Ibid, p. 226
[66] Ibid, p. 229

Beagle's second voyage are unfortunately scant, but despite this, these documents reveal similar negotiations concerning the selection of chronometers, the rates assigned, and, subsequently, the longitudes that were determined.

Fitzroy gave an elaborate explanation of how he rated the chronometers, as I showed in chapter 6, by using Equal Altitudes of the Sun. He felt it necessary to point out that the time determined by these observations differed less than a tenth of a second compared to observations obtained by astronomers at Paramatta Observatory and the Royal Observatory at Greenwich.[67] This indicates how important these observations were for the accuracy of the results of the chronometers; just as important, if not more important, than the internal workings of the instruments. The application of rates to the chronometers on the *Beagle* has been discussed above (chapter 6 pages 225-240). Let me briefly discus the selection of the chronometers.

In the *Appendix*, Fitzroy published only the *results* of his determinations. From this, it is clear that he selected the chronometers whose results lay closer to the mean and rejected those that differed too far from the mean. Table 7.1 is based on two sources: the published appendix and Stokes' notebook. The first column lists all the chronometers used for the meridian distance and the second column shows the results for each instrument. The third column shows the chronometers officially selected to determine the distance and the final column shows Stokes' selection.

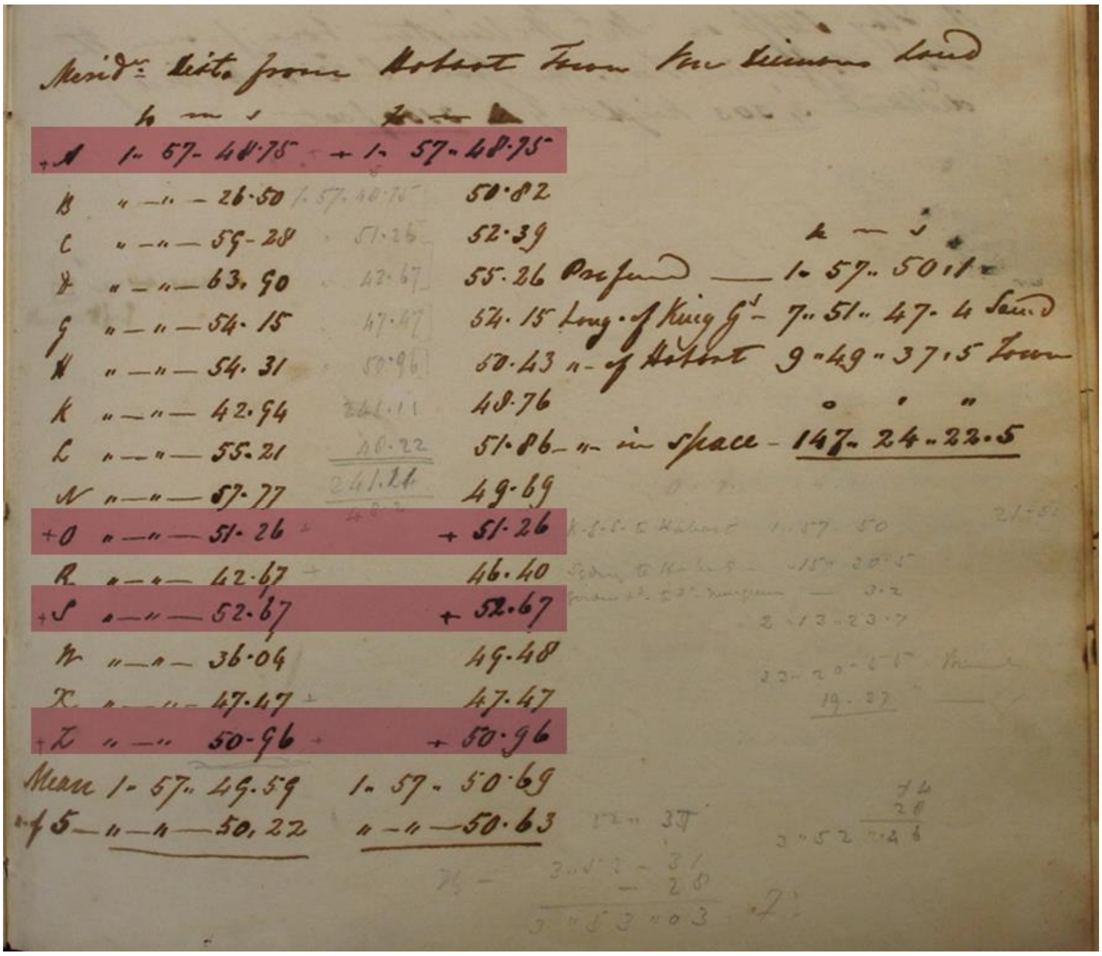
[67] Robert Fitzroy, *Narrative of the Surveying Voyages of his Majesty's Ships* Adventure *and* Beagle *between the Years 1826 and 1836, Appendix to Volume II*, (London: Henry Colburn, 1839), p. 329

In the run from Ascension to Bahia the results were as follows:

	Published Account		**Stokes' Journal**
Chronometer	*All*	*Selected*	*Selected*
A	1.36.27,18	1.36.27,18	1.36.27,18
B	1.36.20,25		
C	1.36.25,75	1.36.25,75	1.36.25,75
D	1.36.28,31	1.36.28,31	
G	1.36.24.47	1.36.24.47	
H	1.36.23,48		
K	1.36.22,36		
L	1.36.28,76	1.36.28,76	1.36.28,76
N	1.36.29,92	1.36. 29,92	
O	1.36.23,56		
R	1.36.26,65	1.36.26,65	1.36.26,65
S	1.36.24,71	1.36.24,71	1.36.24,71
W	1.36.26,28	1.36.26,28	1.36.26,28
X	1.36.32,50		
Z	1.36.26,12	1.36.26,12	1.36.26,12
Mean	1.36.26,02	1.36.26,70	1.36.26,49

Table 7.1: Data from Fitzroy *Narrative of the Surveying Voyages – Appendix to Volume II*, p. 341, and from Stokes' General Notebook. NMM, STK/26/1

As can be seen from the table, fifteen chronometers were used (A – Z): Fitzroy selected the ten instruments he considered the best while Stokes selected only seven. The scant record of meridian distances in Stokes' notebook follow a similar pattern: he selected a lower number of chronometers by which he determined a 'preferred' distance. But was such precision even necessary? As can be seen from this evidence, the difference between these three determinations is extremely small, amounting to merely 0.68 seconds between the greatest two differences. It is also unclear what Stokes' reasoning was for selecting these chronometers and omitting others. Although it is clear that in both selections (i.e. the official selection of ten chronometers out of fifteen and Stokes' selection of seven chronometers), all the chronometers chosen lay closer to the mean result and outliers were excluded, this was not necessarily the only criterion that Stokes applied. The examination of a different meridian distance reveals that Stokes noted two results for the difference in time between Hobart Town and Van Diemen's Land. Figure 7.18 shows the page from Stokes' notebook where he listed the results in two columns. Results in the first column were based on calculations using the mean of the rates determined by observations performed at both locations. In the second column, 'the watches have been rated by the watches that have <u>been going steadily</u>'. These are the highlighted chronometers in figure 7.6 (chronometers A, O, S and Z). As Stokes put it, 'the preference being given <u>to four watches</u> against eleven may appear strange; a strict and careful examination of the comparison book has excused it. The better agreement of the watches in the second column must prove the correctness of it, tho the mean of the <u>five best of each</u> differs only <u>4 tenths</u> of a second'.[68]


Merid: Dist. from Hobart Town Van Diemens Land

	h m s		
+A	1. 57. 48.75	+ 1. 57. 48.75	
B	" — " — 26.50	50.82	
C	" — " — 59.28	52.39	h m s
D	" — " — 63.90	55.26	Preferred — 1. 57. 50.1
G	" — " — 54.15	54.15	Long. of King G's — 7. 51. 47. 4 Sound
H	" — " — 54.31	50.43	" of Hobart 9. 49. 37.5 Town
K	" — " — 42.94	48.76	° ' "
L	" — " — 55.21	51.86	" in space — 147. 24. 22.5
N	" — " — 57.77	49.69	
+O	" — " — 51.26	+ 51.26	
R	" — " — 42.67	46.40	
+S	" — " — 52.67	+ 52.67	
W	" — " — 36.04	49.48	
X	" — " — 47.47	47.47	
+Z	" — " 50.96	+ 50.96	
Mean	1. 57. 49.59	1. 57. 50.69	
of 5	" — " — 50.22	" — " — 50.63	

Figure 7.18: Chronometer selection by Stokes for the meridian distance between Hobart Town and Van Diemen's Land. NMM, STK/26/1.

[68] John Lort Stokes, General Notebook, probably begun circa 1830. NMM, STK26/1

Even with a collection of the best chronometers available, selection was neither simple nor evident. The variations between these results, however slight, reveal that selection was dependent on *who* was doing the selection and *how* the rates had been calculated. Despite these variations being small, they still mattered to those calculating them. Fitzroy and Stebbing came to different conclusions, just as Tiarks altered Foster's determinations by applying a different formula for the interpolation of the rates. Each meridian distance therefore varied, as users selected different instruments, applied different rates and adjusted calculations to align them with other determinations.

The task of collecting and analysing all this information from several voyages faced similar issues. In 1839, prior to publishing his *Practice,* Raper published a paper entitled 'On the Longitudes of the Principal Maritime Points of the Globe'. The paper was published in eight parts, between April and November 1839. He had spent 'considerable time and labor … to establish among the several longitudes, that consistency which the number of observations, now accumulated, gives us a right to expect, at least in some parts of the world'.[69] In addition to this, Raper 'demanded that a list of positions pretending to any claim upon the confidence of seamen, should exhibit both the elements that have entered into its composition, and the use that the Compiler had made of his evidence'.[70] Raper thus called for uniformity in the method of referring data to particular stations. In his *Practice* he attempted to discipline the users to collect data in a specific way, through chronometric instruction, so that the data collected could be readily processed by the Hydrographic Office. His list of maritime positions was compiled from various sources: earlier discussions printed in the *Connaissance des Temps* and the *Astronomische Nachrichten*; 'fresh *data*' that Raper had access to 'by the kindness of Captain Beaufort, (and often with his assistance)'; and

[69] Henry Raper, 'On the Longitudes of the Principal Maritime Points of the Globe', *Nautical Magazine*, April, (1839), p. 260
[70] Ibid, p. 260

finally, from approximately seventy-five voyages whose hydrographical information had been deposited at the Hydrographic Office.[71]

The following section examines this transition from data collected on a voyage in a particular way, through the process of consolidation towards a stabilised fact, i.e., a geographical position of longitude as published in Raper's paper. Raper's list of maritime positions included Owen's, Foster's and Fitzroy's expeditions, but omitted 'the Polar Voyages … as lying too far out of the way of ordinary navigation'.[72] Despite Raper's exclusions of these expeditions, the navigational practices on board Parry's polar expeditions provide clear examples of how data could be collected and was particularly dependent on the individual, the geography of the voyage, and the methods against which the reliability of the instruments were tested.

Coordinating accuracy

Accuracy was found by agreement and place was key to coordinating the efforts to standardise longitude. Navigational manuals commonly included lists containing the latitude and longitude of places around the globe useful to navigation; these were not only listed as a destination, but also for navigators to use as a departure.[73] Many of these positions were inaccurate. This added to the difficulty in establishing where one was and where one was going. It was not until progress in charting had been made that a more accurate determination of these positions became beneficial. Both of these factors, the accuracy of

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[71] Raper, 'On the Longitudes of the Principal Maritime Points of the Globe', p. 260. A complete list of the voyages can be found from page 261 in this edition.

[72] Ibid, p. 261

[73] John Hamilton Moore, *The New Practical Navigator,* sixteenth edition, (London: G. and J. Robinson, 1804); John William Norie, *A New and Complete Epitome of Practical Navigation,* (London: J. W. Norie and William Heather, 1805); Nathanial Bowditch and Thomas Kirby, *The Improved Practical Navigator,* third edition, (London: James and John Hardy, 1809); Edward Riddle, *Treatise on Navigation and Nautical Astronomy,* (London: Baldwin, Cradock, and Joy, 1824).

charts and the positions of latitude and longitude, were imperative for chronometric methods to succeed. Flamsteed had made this point in 1697: 'Tis in vain to talk of the Use of finding the Longitude at Sea, except you know the true Longitude and Latitude of the Port for which you are designed'.[74]

The problem with the chronometer was that alone it was not sufficient for the job at hand. It was a good tool in navigation, where it could function as a more accurate method of dead-reckoning. Its precision also made it highly beneficial when applied to surveying practices: in these situations, the chronometer's function could be said to be 'black-boxed'. The problem was not in the potential precision of the chronometer (potential because the instrument still fluctuated too much in challenging conditions; precise, as it often produced similar results). It lay in the difficulty of judging the accuracy of the measurements it produced. The chronometer was not in itself an accurate instrument, its accuracy depended on what it was intended to measure. In surveying, it was accurate, as it was only relied upon for very short instances of time. The longer the period of time it was to measure, the more its accuracy could be called into doubt. And as the points that the chronometer was intended to measure had not been accurately determined, a back and forth negotiation was taking place. This is why the *Beagle* carried twenty-two chronometers. Had the voyage been limited to surveying the South American coast, four or five may have been sufficient. For the purpose of determining meridian distances, large numbers were required to generate claims to credibility.

The definition of black-boxing as laid out by Latour 'refers to the way scientific and technical work is made invisible by its own success'.[75] This definition applies to these points

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[74] Flamsteed, writing to Pepys on 21st April 1697, quoted in W. E. May, *A History of Marine Navigation,* (Henley-on-Thames: G T Foulis & Co LTD, 1973), p. 29

[75] Bruno Latour, *Pandora's Hope: Essays on the Reality of Science Studies*, (Cambridge: Harvard University Press, 1999), p. 304

of longitude. Raper's lists of maritime positions published in 1839 included descriptions of how these determinations were made. These details included whether they were made astronomically (lunars, eclipses, occultations) or chronometrically, by whom and how the resulting longitude had been calculated. Raper compared the whole to form a determination, which although not itself always accurate, was at least a fixed point of reference for all navigators and surveyors. Gradually, these lists would become fixed positions of longitude, no longer accompanied by a discussion or uncertainty (at least not in the manuals in which they appear). The longitudes in that sense had been black-boxed: that is, the knowledge is now encapsulated in the result, where the complexity of its determination was hidden from view. Longitude became detached 'from [its] context of creation to serve other technical and scientific needs'.[76] Black-boxing the points of longitude meant that, in hindsight, chronometers could be more easily calibrated and, consequently, could form a check on the discipline of users. If the outcome of the chronometric determinations matched that of the longitude, both the instrument and the users had performed as desired.[77] The chronometer thus performed an important role, but not its only one, in hydrography, where points of longitude required the 'progressive stabilization of distinct elements'.[78] The chronometer could not be trusted until the longitude was known: the longitude, as determined by the chronometer, was the only way to judge whether it had been appropriately used.

Raper's 1839 paper in the *Nautical Magazine* is a good place to unpick this constructed longitude. I examine this by focusing upon Raper's discussion of the longitude of Rio de Janeiro. The longitude of Rio de Janeiro was a point of contention in British and foreign naval circles. The determinations made by Owen, Baron de Roussin and 'the Portuguese

[76] Davis Baird, *Thing Knowledge, A Philosophy of Scientific Instruments*, (Berkeley and Los Angeles: University of California Press, 2004), p. 163
[77] Jan Golinski, *Making Natural Knowledge: Constructivism and the History of Science*, (Cambridge: Cambridge University Press, 1998), p. 141.
[78] Golinski, *Making Natural Knowledge*, p. 140

astronomers' did not agree with those of Foster, King and Beechey. Beaufort wished to verify the matter since 'all our meridian distances in South America are measured from thence'.[79] Supplied with the best chronometers, Beaufort hoped the matter could be settled during the *Beagle's* voyage. His instructions to Fitzroy were to break the run down into parts. There were several reasons for this. Dividing the run into parts meant that rates could be obtained at each stop and alterations due to temperature variations could be monitored, so allowing the difference between the authorities to be reduced to 'within limits too small to be of much import in our future conclusions'.[80] The first port of call was Madeira, 'the exact position of which has been admitted by all parties'.[81] For this reason, it could serve as one of Raper's *secondary meridians*, i.e. a point of longitude assumed as 'a fundamental point' to which all further positions would refer.[82] The second port of call was Port Praya (Cape Verde), an important station for the longitudes submitted by Captain Owen, and one that Beaufort felt required verification. Beaufort selected Fernando Noronha as the next stop, which neatly divided the run into three equal parts and formed an important station in Foster's determinations. This part of Fitzroy's journey involved corroborating various accounts. Beaufort recommended astronomical observations ('eclipses, occultations, lunar distances, and Moon-culminating stars, will furnish those means in abundance: of all these, the last can be obtained with the greatest regularity and certainty') as 'absolutely necessary' because the chronometers would be in use for long periods and subjected to sudden changes of heat and cold.[83]

Despite Beaufort's specific instruction as to the necessity of astronomical observation, Fitzroy concentrated on the chronometric differences alone, 'having so many good

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[79] Fitzroy, *Narrative of the Surveying Voyages Appendix to Volume II*, p. 24
[80] Ibid, p. 25
[81] Ibid, p. 25
[82] Raper, 'On the Necessity of Adopting Secondary Meridians', p. 400, emphasis in original
[83] Fitzroy, *Narrative of the Surveying Voyages Appendix to Volume II*, p. 36

chronometers on board; being practised in observations such as they require; and placing great confidence in their results' rather than 'to perplex myself … by attempting series of observations which would give occupation to an astronomer, and could not be undertaken by me, while actively engaged in coast-survey, without interfering with other duties'.[84] Poor weather conditions, a transit instrument 'of inferior construction' and the time required to adjust the instrument and wait for clear skies were additional reasons for Fitzroy to ignore these astronomical duties.[85]

Raper continued the discussion of the longitude of Rio de Janeiro by pointing out the 'very great anomalies' between various determinations.[86] In discussing the validity of a point of longitude, Raper made clear that secondary meridians should be determined by astronomical observations which could then be connected chronometrically with other places. These astronomically determined positions could then be connected chronometrically to surveys across the globe. Corrections in relation to one of the secondary meridians could be transferred through these connections to any other places affected. Raper also elaborated on the difficulty of judging the results: 'when two or three successive determinations agree nearly together we are apt to assume in general that they are right. This is however by no means certain', he continued, citing the example of the difference of longitude between Greenwich and Paris, 'in which two or three equally bad results will often be found following each other. It is therefore open to discussion whether the first determinations of a place, even though they agree, are right or wrong'.[87] Raper did believe however, that if determinations differed widely from one another, then the truth was likely

[84] Fitzroy, *Narrative of the Surveying Voyages Appendix to Volume II*, p. 75
[85] Ibid, p. 74
[86] Henry Raper, 'On the Longitudes of the Principal Maritime Points of the Globe', *Nautical Magazine*, October, (1839), p. 698
[87] Henry Raper, 'Discussion of the Longitudes of the Principal Maritime Points of the Globe', *Nautical Magazine*, July, (1839), p. 476

to be found somewhere 'between them, because such great discrepancy most probably arises from the presence of errors of opposite kinds'.[88] In some cases, however, Raper suggested that 'the evidence divides itself in support of two distinct determinations … in such cases the probability seems to be that one of the determinations is true and the other false'.[89] Rio de Janeiro was one such case. The point of observation, was Fort Villgagnon, recorded as 43°8' on English charts and 43°14' on French charts. Determinations of this place varied up to 40', and 'even in our own times, the results of large numbers of chronometers' had not managed to settle the debate without a difference of 10' between them.[90]

The problem with this station, as Beaufort also noted, was that it formed the reference meridian for many other places. Raper hoped to solve the problem by supporting Beechey's determinations (by Moon culminating stars) with chronometric differences from other places, particularly from where the longitude was 'well determined'. Raper's discussion of Rio de Janeiro was a lengthy and complicated one. But if we break it down, we can see how distinct elements became stabilised, to use Golinski's term.[91] Raper relied on astronomical determinations made in various ports on the South American coast and the difference of longitudes between these places determined during the previous fifty years by French, German, British and Portuguese astronomers. The majority of the determinations were astronomical, involving transits of Mercury, lunars, the solar eclipse of 1784 and occultations of fixed stars. In 1830, M. Givry, the French Hydrographer, discussed these results in the *Connaissance des Temps*. Comparison led to agreement, which led Givry to confirm the longitude of Rio de Janeiro as 44°32'33". Raper resumed this discussion, adding the longitude of Fort Anhatomirim (48°34'20") as determined by Beechey in 1836 and connecting this to

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[88] Raper, 'Discussion of the Longitudes of the Principal Maritime Points of the Globe', July, p. 476
[89] Ibid, p. 476
[90] Raper, 'On the Longitudes of the Principal Maritime Points of the Globe', October, p. 699
[91] Golinski, *Making Natural Knowledge*, p. 140

Fort Villgagnon by their difference of longitude. For this difference, Raper listed six sources: Foster, King, Roussin, Givry, Beechey and Fitzroy from whose six determinations he took the mean. In this discussion, each separate determination was given equal weight. The mean result of this was 5°25’3” which led to the longitude of 43º9’ (by deducting 5°25’3” from the longitude of Fort Anhatomirim: 48º34’20”) for Rio de Janeiro. The goal in view was practicality rather than accuracy. Whether the absolute longitude of Rio was really 43º8’ or 43º14’ was not the point. The point was to accumulate comparable data from different sets of users, select an agreed value and then have all navigators use this value.

Ascension Island was another point of longitude that demanded Raper’s attention, but, as with Rio de Janeiro, it was not discussed in isolation. Raper came to the following view:

> The remarkable agreement of Captain Vidal's chronometric runs during long intervals gives great weight to his connection with Sierra Leone, and this last position agrees singularly well with Captain Owen's determination made 12 years before. Sierra Leone is determined probably to 2 or 3 seconds of time. Again, the meridian distances of St. Helena and Ascension agree remarkably well. Now on this run Captain FitzRoy's chronometers vary only four seconds, while on the run from the Cape to St. Helena they vary sixteen seconds, hence the connection between Ascension and St. Helena is more certain than that between St. Helena and the Cape. If now we apply 8°41'40" above, to 5°42'47", we obtain 14°24’27", combining this with 14°26'9" (the joint result of Owen's and Vidals') and giving double weight to this result, we obtain 14°25'35" and hence from St. Helena 5°43'55", which very nearly agrees with observation.[92]

The figure of 8°41'40" was the mean of the chronometric determinations of both Fitzroy and Foster between St Helena and Ascension. The longitude of the Observatory on St Helena was determined as 5°42'47", also by the mean of Fitzroy’s and Fosters chronometric determinations. Vidal’s and Owen’s determinations were given more weight than those of Fitzroy and Foster due to their ‘remarkable agreement’. The resulting longitude of all the observations and calculations placed Ascension at a longitude of 14°25'35". By subtracting the difference of longitude between St. Helena and Ascension (8°41'40") from this, the

[92] Raper, ‘On the Longitudes of the Principal Maritime Points of the Globe*’, Nautical Magazine,* August, (1839), p. 548

longitude of the observatory on St. Helena was corrected to 5°43'55" (rather than 5°42'47" as determined by Fitzroy and Foster) which, Raper concluded, 'very nearly agrees with observation'. Observation, in this case, was determined by '54 observations of Moon culminating stars compared with observations at Greenwich, Cambridge, and Cape of Good Hope'.[93] In Raper's *Practice of Navigation,* this longitude had already been adjusted to 5°44'00".[94]

The above examples have been chosen to show how complex longitudinal determinations were. Each determination was evaluated in comparison to other determinations, either chronometrical or astronomical, whether performed by a surveyor, an astronomer, or a naval officer. This brings back into focus Miller's point: 'neither technological determinism identifying an instrument as *the* solution, nor singular method determinism, captures how longitude was established in practice'.[95] This also echoes Phillips' point that the longitude problem was one of 'regulating and rating', and an 'appropriate astronomical technique'.[96] What is missing from this is the role of the Hydrographic Office where the accumulated data was not only stored, but also analysed and disseminated to officers in the Royal Navy and merchant marine. Increasingly, the Hydrographic Office supported an open exchange of knowledge and the 'intention to "diffuse" it'.[97] That Raper's first call to regulate maritime positions was published in the *Nautical Magazine* is indicative of this. The *Nautical Magazine,* edited by Alexander Becher at the Hydrographic Office under Francis Beaufort's supervision and with the financial support of the state, was 'an organ for

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[93] Raper, 'On the Longitudes of the Principal Maritime Points of the Globe', August, p. 548
[94] Raper, *The Practice of Navigation,* (1840), Tables, p. 86
[95] David Phillip Miller, 'Longitude Networks on Land and Sea', *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds. (Basingstoke: Palgrave Macmillan, 2016), p. 224
[96] Eóin Edward Phillips, *Making Time Fit: Astronomers, Artisans and the State, 1770-1820, Unpublished Thesis,* University of Cambridge, (2014), p. 199
[97] Megan Barford, 'Fugitive Hydrography: The *Nautical Magazine* and the Hydrographic Office of the Admiralty, c. 1832-1850', *The International Journal of Maritime History*, 27, (2015), p. 217

the dissemination, but also crucially for the collection, of useful knowledge in its desire to improve the Royal and Merchant Navy'.[98]

Conclusion

Officers using chronometers to calculate longitude or differences of longitude would constantly evaluate the accuracy of their instruments even as this was dependent on the resources to which they had access in the field. This chapter has focused on how these checks were applied in the field. Parry's three northern expeditions form an interesting case study as each expedition set out with the same goals, instruments, instructions and a similar crew. Nevertheless, the steps taken to calibrate and calculate the chronometric measurements varied considerably. In these cases, this was linked to the astronomical abilities of the accompanying observer and their views on how steady and reliable they considered the rates of the chronometers. Sabine, dedicated as he was to pendulum research, was perhaps less experienced in the practice of particular astronomical observations, but he also did not deem it necessary as a check on the chronometers: in his words, he was never 'able to discover any systematic variations whatever' when using chronometers supplied by Parkinson and Frodsham, on ship or on shore.[99] His views on whether magnetism influenced the going of chronometers or not were decisively dismissive of this possibility. Fisher and Foster both conducted more varied astronomical observations on shore, and in Fisher's case there is evidence to suggest that he placed less trust in the stability of his chronometer rates and spent more time improving the accuracy of his measurements with astronomical and mathematical techniques.

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[98] Barford, 'Fugitive Hydrography: The *Nautical Magazine* and the Hydrographic Office of the Admiralty, p. 209

[99] 'Marine Chronometers, and Currents of the Ocean', *The Kaleidoscope: or, Literary and Scientific Mirror*, 6 September 1825, p. 271

Astronomical observations on shore played a crucial role in early nineteenth-century chronometry. Foster's voyage has shown how establishing the longitude on land to rate chronometers was complicated and challenging. Improvisation was often required and only skilled observers could be trusted with this task. Foster used the observations to calibrate his instruments, which he did both on arrival and on departure. The influence of observatory practices on Royal Navy expeditions went beyond the introduction of astronomical and chronometric procedures for longitude as it extended to the methods of observation performed by naval officers on distant shores and introduced 'a standardised system of calculation' in the reduction of the results.[100] As Phillips has concluded, '[the] work and experience of astronomers demonstrated the ways in which establishing forms of trust and disciplined reporting from officers came to be more important for the Board of Longitude and the Admiralty than reliance on 'perfect' instrumentation'.[101] However, this still left room for interpretation. In the examples shown in this chapter, the officers following instruction were trusted to improvise whilst working in the field. This is similarly evident in Raper's discussion of 'The Principal Maritime Points'. The reliability of the results produced by Foster, King, Fitzroy, Owen and others was not questioned since it was expected that their determinations would vary. Raper's task was to find agreement between these varying results.

We have seen how rates and errors were established through astronomical observations on shore and by comparison at sea. Rates could vary considerably between two stations and it was down to the user to determine how a correction should be applied. As a result, two different observers could come to different conclusions on what the correction should be. Instruments could be either included or excluded from the mean. Different results

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[100] William J. Ashworth, 'The Calculating Eye: Baily, Herschel, Babbage and the Business of Astronomy', *British Journal for the History of Science*, 27, (1994), p. 411
[101] Phillips, *Making Time Fit*, p. 18

were compared based on calculations using only the rates determined on departure, those determined on arrival, and from the mean of the two. Foster, Tiarks, Fitzroy and Stokes all came to different conclusions as their reasoning for selecting a method varied. As Withers has emphasised, '[imprecision] and confusion in geography and in time was, it turned out, an almost unavoidable consequence of the numerous methods and metrologies used to determine the different points and lines in space'.[102]

Advances in hydrography could not occur until the longitude of specific locations had been agreed, against which the chronometers could be checked. The voyage of the *Beagle* was the first to connect a chain of meridian distances around the globe, but this did not mean that the positions determined were accepted as fact. As has been shown throughout this thesis, calculating longitude by chronometer was both time-consuming and a complicated process. This chapter has shown that this process continued long after the expeditions returned to England, with the accumulation and comparison of data generated by voyages spanning over half a century in time. Nevertheless, through continued collection, collaboration and comparison, agreed points of longitudes were slowly worked out from the mass of documents deposited at the Hydrographic Office. Continued negotiation – between methods, instruments, voyages, shore and sea-based observations – ensured that the data collected at sea allowed the globe to be mapped to ever increasing accuracy. To this end, Raper considered fixed points of longitude determined by astronomical observations crucial to improving hydrography. Agreement on fixed points of longitude formed a check on chronometers and provided anchor points for chronometric connections. From the 1830s, these fixed points would increasingly be equipped with time-balls, which reduced the reliance on astronomical observations.

102 Withers, *Zero Degrees*, p. 115

Raper's paper was addressed to naval men in general. For those not skilled in various branches of astronomy, or equipped with precision instruments, discipline and instruction were vital to increase the production of reliable data at sea. Precision navigation helped 'make visible and thus control' the performance of officers.[103] Raper's list of 'Maritime Positions' would allow more individuals to contribute to the collection of data that could then be evaluated by others at the Hydrographic Office. This shows parallels with the management regime of the Royal Observatory under George Biddell Airy where 'moral discipline went hand in hand with quantitative discipline'.[104] In summary, this chapter has shown how through negotiation, longitude could be agreed. These agreed reference points made calibrating chronometers easier for officers. They led to a more systematised method of data collection and a means to check and control the performance of both instruments, and their human operators.

[103] Phillips, *Making Time Fit*, p. 17/18

[104] Simon Schaffer, 'Astronomers Mark Time: Discipline and the Personal Equation', *Science in Context*, 2, (1988), p. 121

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Conclusion

> Whatever value may be attached to Chronometric results, the objection cannot be removed, at least at present, that any cause which affects the rate of one watch, may with equal probability affect any number however great in like manner; thus rendering the consistency of several watches no argument for the truth of the time they show. But whatever results the continual efforts to perfect the machinery may tend finally to produce, the very imperfection of watches at present contributes to the security of navigation; for since one watch often loses, while another under exactly the same circumstances gains, the discrepancies prevent the danger of trusting too confidently to any one result.[1]

Introduction

Henry Raper's remarks above were made over a century after the first sea trial of John Harrison's marine timekeeper, known now as 'H1'. In the decades between, much had changed in the practice of chronometry and the calculation of longitude. In 1762, the sea trial of John Harrison's fourth marine timekeeper, 'H4', proved that a single piece of marine timekeeping technology could aid navigators in determining longitude at sea. By 1836, a single naval voyage carried twenty-two marine chronometers that were used to determine a global chain of meridian distances. In the intervening years, the design and principles upon which marine chronometers were built had changed and improved. The cost of individual instruments had been reduced, and the supply of these devices to the Royal Navy had increased. However, one crucial element remained the same: chronometers were still susceptible to variations in the shipboard environment and users could not always be sure that the rate and thus error of a chronometer could be predicted with absolute certainty. As

[1] Henry Raper, 'Remarks on the Modes of Determining Longitude', *Nautical Magazine*, May, (1839), pp. 324-325

a result, even towards the later 1830s and 1840s, chronometers still remained ‘suspect’, at least that is, as Raper’s quote suggests, when only one was used or when chronometry was used in isolation. Raper’s remarks thus point to a number of the main findings of this thesis: that the chronometer was successful when it was used in association with other means of calculating longitude, when more than one chronometer was employed on board ship and when chronometry was the result of networks which supported its use. Raper’s remarks must also be read in relation to his own published list of longitudes, which he encouraged others to adopt in his efforts to standardise the collection of hydrographic data and thereby improve navigation.[2] Here, too, we can see a connection with the findings of this thesis, namely, the link between chronometry at sea, navigation manuals and the production and dissemination of chronometric data.

This thesis set out to investigate the use of chronometers on board Royal Navy expeditions in the early decades of the nineteenth century. To gain a comprehensive understanding of chronometry at sea, I have examined the chronometer in context, or rather, in action.[3] This meant examining chronometry as a process: from its start, with the issuing of the chronometers at the commencement of a voyage, to its journey’s end, when the chronometer was returned and the data accumulated during its journey was analysed and, potentially, recast into navigational data. The voyages examined were specifically selected because of the ‘thickness’ of the archival resources relating to their use. I have examined archival sources that are often overlooked within chronometric research: the navigational notebooks containing the observations, calculations, corrections, and outcomes of chronometric practices at sea. In addition to these I consulted journals, the published narratives of expeditions, correspondence, newspapers and literary journals, navigation

[2] Henry Raper, *The Practice of Navigation and Nautical Astronomy*, (London: R. B. Bate, 1840)
[3] Bruno Latour, *Science in Action*, (Cambridge Massachusetts: Harvard University Press, 1987)

manuals, printed chronometric instructions, and additional material. These sources provide a more complex and detailed account of chronometry at sea.

The aim of the thesis was to extend and deepen our understanding of how the chronometer was used at sea, and to illuminate its use within established and expanding practices of navigation with a particular emphasis upon how users learnt to operate it and how they dealt with the vagaries of its use. A second aim was to understand how the chronometer went from being an innovative and to some degree experimental instrument used on pioneering voyages of exploration, to one that was used, by the 1840s, as a standard navigational tool. This thesis argues that certain voyages of exploration were instrumental in aiding the up-take of chronometers at sea and that they did so in a number of ways.

This final chapter is divided into five sections with the collective purpose of identifying the context to the work and to present the principal findings and to address their implications. In the first section, I reiterate the complex and interwoven nature of chronometry and astronomy. These voyages either employed astronomers to assist in astronomical observations and chronometric measurements, or they were commanded by naval officers who had been specifically instructed in these techniques, often, but not always, by those same astronomers. The social status of these officers allowed them to set standards, and to make judgements concerning the use and maintenance of chronometers that others would later follow. In the second, I reiterate the importance of the care and management of instruments, as chronometry in the field was, still, at an experimental stage. This section examines the chosen voyages as sites of experimental practice where officers were testing the pitfalls and difficulties of chronometer use in a shipboard environment and coming up with experimental solutions to perceived problems. Ultimately, as I have shown, this led to the formulation and implementation of increasingly standardised rules that regulated officers in the use of chronometers and which guided their processes of collecting and analysing data. Each of these points is elaborated upon in what follows. In the third section, I reflect on the importance of chronometric data, on how it was collected and managed at sea, and how it was transformed into navigational knowledge that, in time and once ratified, found its way back to sea. The fourth section describes the limitations of the research and suggests areas for future research. In the fifth and final section, I reflect on the key contributions this thesis has made to the history of navigation and the history of chronometry and to the understanding and content of a perhaps more expansive historical geography and history of science and technology.

Astronomical chronometry

This thesis has contributed to a broader understanding of the relationship between astronomical techniques and the implementation of chronometric practices at sea. It has done so by examining this relationship from various perspectives. It includes the connections between astronomical training and its application to chronometer use; the unreliability of the instrument and thus the necessity of astronomical observations to evaluate its performance; and the hierarchies that were perceived between astronomical and chronometric determinations and how this guided and shaped chronometer use. In this sense, the thesis builds upon and extends recent research into the British Board of Longitude and Richard Dunn and Rebekah Higgitt's *Navigational Enterprises in Europe and its Empires, 1730-1850*.[4]

Those officers using chronometers at sea to determine their longitude at sea, or the longitude of distant shores, were required to understand and apply astronomical methods and procedures. Many of these techniques related to other methods of determining

[4] Richard Dunn and Rebekah Higgitt, eds. *Navigational Enterprises in Europe and its Empires, 1730-1850*, (Basingstoke: Palgrave Macmillan, 2016)

longitude, including lunar observations. Even as this was true, lunar observations and chronometers are still often represented as two competing methods which were developed in the eighteenth century to find longitude at sea. This thesis has offered a contrary view. By examining the methods of instruction and training that were available to chronometer users in the early nineteenth century, it has shown how chronometer users were likely to benefit from training and instructions relating to the lunar distance method. While there is clear evidence that chronometers were used more commonly on routine voyages of navigation from the 1780s, it is also clear that within general navigation manuals instructions concerning their use remained limited until the 1810s and 1820s. Most early manuals described chronometers as being both too expensive and too unreliable for use at sea. Nevertheless, detailed instructions relating to timekeeping at sea can be found within the sections given over to calculating the longitude by lunar observations, as is apparent, for example, in Andrew Mackay's of 1793.[5] The presence of these sections within navigational works points to the importance of lunar observations, not only as a complementary method for finding longitude at sea, but also as fundamental for training and instruction and in the acquisition of skills required for the proper and best use of chronometers. Training of officers in lunar distances did not rely solely on navigation manuals: practical instruction would have been equally important. Yet, the skills learnt in the process of taking and recording lunar observations were also drawn upon by chronometer users. The instructions issued to astronomers and captains of ships also point to the importance of astronomical understanding and to the observational skills required in using chronometers. Alexander Dalrymple and William Wales, for example, both emphasised the terms and procedures that would have been familiar to astronomers, if less so to naval officers. These instructions were

[5] Andrew Mackay, *The Theory and Practice of Finding the Longitude at Sea or Land, Volume I*, (London: Printed for J. Sewell, 1793), pp. 64-156

issued to those voyages that were specifically equipped to trial these methods in the late eighteenth century, voyages on which an astronomer was often present. While it was the officers who set the rules and procedures for chronometric use at sea, they were increasingly guided by means of word of mouth, practical example, and in text books, by astronomers and mathematicians.

These reflections on the nature of the training of officers and their use of instruments also points to the social standing of the Royal Naval officer and his access to training and resources. The period of peace following the end of the Napoleonic Wars in 1815 and Britain's naval dominance thereafter also signalled a change in the nature and direction of the Royal Navy. Scientific pursuits at sea afforded good career opportunities for officers skilled in navigation, astronomy and hydrography. The majority of those naval officers who operated within state- and Admiralty-sponsored networks were afforded access to various resources, including scientific instruments and the training and instructions to use them. At sea, the role of the naval officer itself was changing, and this reflected the change that occurred within the scientific communities of London. Early nineteenth-century scientific pursuits, specifically for officers in the Royal Navy, increasingly involved collecting large amounts of data, by taking multiple observations and measurements using precision instruments. This speaks to Shapin's argument that access to the spaces where technology and science were practised is key to understanding how and why certain practices were adopted.[6] In these select spaces such as the captain's cabin, the quarter deck, even the shore-based observatory tent, Royal Society observers could train naval officers to become observers themselves, as Michael Bravo has shown.[7] In the context of this thesis, I have

[6] Steven Shapin, *Never Pure: Historical Studies of Science as if It Was Produced by People with Bodies, Situated in Time, Space, Culture, and Society, and Struggling for Credibility and Authority*, (Baltimore: The John Hopkins University Press, 2010), p. 57

[7] Michael Trevor Bravo, *Science and Discovery in the Admiralty Voyages to the Arctic Regions in Search of a North-West Passage (1818-25)*, Unpublished PhD, University of Cambridge, (1992), p. iii

shown how this was also the case in chronometry and navigational science. This collaborative element of training and instruction in specific sites between people with the appropriate social status lent authority and credibility to the resulting practices. William Edward Parry, Edward Sabine, George Fisher and Henry Foster were, for example, all associated in one way or another with the training and experimental space that was Henry Browne's basement, an 'informal and extremely elite private space' in which Admiralty officers were trained by Henry Kater of the Royal Society.[8] There, they became fully acquainted with scientific instruments and with the training required in their use. Under Parry's command in the Arctic, junior officers were similarly instructed in, and assisted with, their astronomical observations. This was a crucial part of their training in nautical astronomy.

This thesis has shown that this increased competence amongst some officers in astronomy, navigation and chronometry was not always and everywhere extended to all on board ship. As William Fitzwilliam Owen testified in his journal, few of his junior officers had any knowledge or experience of astronomical science. In modern scholar ship, Betts cites a captain who, in 1836, stated that he regularly encountered fellow captains who had been issued with chronometers but who had no idea how to use them and did not understand that it would take time to do so.[9] Although Betts concludes that this view was not commonplace became increasingly rare overtime, the evidence presented in this thesis suggests that this may have been quite common, more so than hitherto assumed perhaps, in the 1830s. But a note of caution is necessary here. This study has focused on particular expeditions and upon particular source material. Further research into the general adoption of these methods of

[8] Sophie Waring, 'The Board of Longitude and the Funding of Scientific Work: Negotiating Authority and Expertise in the Early Nineteenth Century', *Journal for Maritime Research*, 16, (2014), p. 109
[9] Jonathan Betts, *Marine Chronometers at Greenwich, A Catalogue of Marine Chronometers at the National Maritime Museum, Greenwich*, (Oxford: Oxford University Press, 2017), p. 59

calculating longitude as sea is necessary before we can make solid judgements about the degree of their take-up across the Navy as a whole.

Astronomical observations remained a fundamental aspect of chronometry because although chronometers were issued more widely by the early nineteenth century, they were still considered unreliable. This thesis has shown that chronometric procedures and determinations were dependent upon lunar and other astronomical observations to a considerable degree. First and foremost, astronomical observations were still necessary to establish onshore determinations of longitude, against which chronometers could be calibrated. In some parts of the world, overseas observatories could provide this service to naval officers, but for most expeditions, these services were not available. These links to observatories, in particular to the Royal Observatory, were secured and made stronger by reference to publications such as the *Nautical Almanac* and the *Tables Requisite.* These publications are commonly seen as important to the method of calculating longitude by lunar distances, as indeed they were, but they were also essential for those officers using chronometers at sea as the texts contained the necessary corrections for refraction, dip, parallax, semi-diameter and the Equation of Time. The findings of this thesis in this respect thus complement and extend recent work in the history of navigation.

Instruments of precision or unruly technology?

This thesis has shown that uncertainties surrounded the use of chronometers at sea. Why chronometers varied in their rates or even stopped working at sea was not fully understood. It was because of these uncertainties that officers experimented in different ways in order to manage and to care for the instruments under their charge. As a result, how instruments were managed at sea depended on what was thought to be the root cause of the problem, whether this was magnetic interference, the result of temperature variations or a consequence of chronometers being improperly moved or mishandled. The evidence presented here demonstrates that considerable efforts were made to ensure that they worked optimally and to prevent either human or instrumental failure that was common in chronometers' use at sea. The four case studies make clear that how chronometers were cared for and managed was contingent on a variety of factors.

The Royal Observatory at Greenwich became an important authority in terms of ensuring the working status of chronometers used at sea. The chronometers issued to these voyages had been tested by methods and procedures formulated by astronomers and mathematicians, in the Premium Trials conducted at the Royal Observatory in Greenwich. These trials encouraged chronometer makers to improve the mechanisms of the chronometers and as a result the quality of government owned chronometers improved. This also put the Royal Observatory and the Astronomer Royal at the centre of the testing and issue of chronometers. Those chronometers that performed best in these Premium Trials were reserved for officers on the most prestigious scientific expeditions. Makers would also use this opportunity to have their own instruments tested on these prestigious voyages. Whether their methods of testing were approved by all did not matter (consider James South's critique in chapter 3 pages 71-72). What mattered was that the captains who were issued with these instruments considered them superior to other instruments. As a result, the determinations of longitude derived from these instruments and from these ships were granted a certain authority, epistemic and social, that others were not. Here, we again see the role of authority and trust: the authority of the Royal Observatory to test and issue these instruments, and the trust placed in the officers they were issued to, and the techniques that these officers applied.[10] Eóin Phillips demonstrated how initially, lunar observations and

[10] Steven Shapin, 'Placing the View from Nowhere: Historical and Geographical Problems in the Location of Science', *Transactions of the Institute of British Geographers*, 23, (1998), pp. 7-8

chronometers were entrusted to astronomers appointed by the Board of Longitude, as they were trusted to perform, and to train others to perform, these duties.[11] This thesis has shown how through education, training and discipline, naval officers were eventually trusted to perform and instruct others in these duties themselves.

Observations in the field were considerably more difficult in practice than on paper. Poor weather hindered observations; bad weather prevented them altogether. In the Arctic, observers experienced burning sensations when using cold instruments, which often froze and broke down in the extremely low temperatures. Here, the atmosphere distorted the appearance of the surroundings, further adding to the difficulty of observing in the field. Even in milder conditions, instruments failed and broke down. Officers in the field learnt to deal with, and mitigate these problems, as, for example, Parry's use of heated tin cans for observing with pocket chronometers has shown.

This thesis has shown that different practices were adapted to respond to the specific environment of a particular ship, the particular geography or area visited and the perceived problems which officers felt had to be mitigated. This meant different things in practice. Some officers on some expeditions believed it sensible to suspend the chronometers from slings. Others thought that this was detrimental to their going and considered a gimballed table structure the only way to prevent instrumental error. Even if this was considered best practice, it was not always practical: working with twenty-two chronometers on board, Fitzroy made do with fixing the chronometers to shelves. This reflected Fitzroy's beliefs on how chronometers were affected by their environment. His view was that movement had no effect on their going, and that the main cause of irregularities of rate was variation in temperature. William Fitzwilliam Owen established practices that mitigated the effects of

[11] Eóin Phillips, 'Instrumenting Order: Longitude, Seamen and Astronomers', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. F. Withers, eds, (Abingdon: Routledge, 2016), pp. 162-163

movement, which he considered the most detrimental to the functional operability of chronometers, by requesting and using a range of hack or deck watches, which allowed him to keep what he considered his superior instruments below decks. This reflected the nature of the survey: much work was done in boats away from the main vessels. In summary, officers applied different measures to protect their instruments from disturbance, whether the source of this was temperature, magnetism, movement, or even the Harmattan winds. These issues were still being debated and tested in the late 1830s, on land and at sea, often instigated by the Astronomer Royal or the Hydrographer, Francis Beaufort, in attempts to improve the accuracy of chronometric measurements.

Trust in an instrument's reliability was also a contingent factor. Trust in the device varied and depended on where and by whom it was issued, whether it had been tested (either on land or at sea) and whether it had been rated on shipboard or on shore. Owen had a clear hierarchy of use in his practice of chronometry, and only considered chronometers issued by the Admiralty and supplied from London to be used as the standard to which all measurements were compared and adjusted. In other cases, the officers were supplied with larger numbers of government trialled and tested instruments, and as a consequence perhaps saw a less rigid hierarchy of status in their chronometers. Trust in a device also varied if the instrument had been repaired, especially if it had been overseas. Owen did not consider such instruments reliable. Fitzroy and Foster saw no problem in having their chronometers repaired on shore: it was a necessary running repair. As always, a daily account of their rates was kept and if these did not vary overmuch, the device was trusted enough to provide dependable measurements. These findings resonate with current research that discusses the difficult nature of instrumental practices at sea and how users struggled to maintain and demonstrate the credibility of their findings despite instrumental failures.[12]

In addition, and in order to prevent or at least reduce instrumental failure, Richard Owen offered guidelines on where chronometers should preferably be kept depending on the type of ship, and advised that they be kept as near to the centre of motion as possible and to avoid having them connected to decks on which guns or chains might cause vibrations. Despite these guidelines, neither William nor Richard Owen specified where they kept their chronometers on board the *Leven* or the *Barracouta*. Of the other expeditions examined, the chronometers were kept in the captain's cabin. This in all probability had more to do with questions of access and authority than with where might be the best place on the ship in terms of instrumental stability, although the captain's cabin was perhaps also that part of the vessel least disturbed by vibrations and movement. The care and management of chronometers can therefore be linked to questions of access, authority, trust and credibility. As the chronometers were kept in the captain's cabin, this meant access was restricted to those officers who walked the quarter deck. This not only limited physical access to the chronometers, but embraced other resources that were required to use them, for example, the use of additional instruments, and access to books, notebooks and paper for recording measurements. Limiting this physical access meant that the practice of chronometry at sea could only be conducted by officers. In a sense, therefore, this meant that this 'knowledge

[12] Richard Dunn, 'North by Northwest? Experimental Instruments and Instruments of Experiment', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016) pp. 57-75; Stuart Jennings, 'Chronometers on the 1821-26 Royal Navy African Survey', *Antiquarian Horology*, 40, (2019), pp. 200-214; Mathew Goodman, 'Proving Instruments Credible in the Early Nineteenth Century: The British Magnetic Survey and Site-Specific Experimentation', *Notes and Records of the Royal Society*, 70, (2016), pp. 251-268; Sarah Louise Millar 'Science at Sea: Soundings and Instrumental Knowledge in British Polar Expedition Narratives, *c.*1818-1848', *Journal of Historical Geography*, 42, (2013), pp.77-87; Charles W. J. Withers, 'Geography and "Thing-Knowledge": Instrument Epistemology, Failure, and Narratives of 19th-Century Exploration', *Transactions of the Institute of British Geographers,* 44, (2019), pp. 676-691

was constructed at a distance', as these officers worked with and received their instructions and training from institutions such as the Royal Society and Board of Longitude, or individuals linked to these institutions, and in close quarters within quite confined spaces on the ship.[13]

As I have shown, connections to institutions and societies lent authority to the officers appointed on these expeditions: they had the authority to judge the merits of their instruments, to implement their own standards of management, and the authority to record and organise the results of chronometric measurements. But adopting strict practices of management also afforded credibility and authority to the voyage itself. It demonstrated that the users understood the instruments; that they understood the limitations of chronometers and applied what they considered appropriate measures to minimise or mitigate these limitations. These issues reflect similar findings in current research and contribute to understanding the complex nature of instrument epistemology, that is, the 'intimate associations between embodied procedure, authority, accuracy, and disciplinary practice'.[14]

In this light, Richard Owen's instructions to navigators achieved two goals: first, they validated William Owen's claims to accuracy, as these instructions were printed as a preface of his tables of latitude and longitude. William Owen wanted navigators to use his tables as a reference, alongside Richard Owen's instructions as a method of use. Second, the instructions provided a disciplinary model which would ensure 'modes of commensurability between distant places', whether these were made by officers with the best quality instruments available or by officers commanding routine voyages of navigation.[15] William

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[13] Simon Naylor, 'The Field, the Museum and the Lecture Hall: The Spaces of Natural History in Victorian Cornwall', *Transactions of the Institute of British Geographers*, 27, (2002), p. 495

[14] Fraser MacDonald and Charles W. J. Withers, 'Introduction: Geography, Technology and Instruments of Exploration', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds, (Abingdon: Routledge, 2016), p. 6

[15] Marie-Noëlle Bourguet, Christian Licoppe and H. Otto Sibum, 'Introduction', in: *Instruments, Travel and Science: Itineraries of Precision from the Seventeenth to the Twentieth Century*, Marie-Noëlle Bourguet, Christian Licoppe and H. Otto Sibum, eds, (London: Routledge, 2002), p. 9

and Richard Owen relied on textual means to demonstrate and persuade others of the validity of their claims.[16] These instructions meant that anybody with a chronometer could collect chronometric data, and that this data could then be compared and analysed with that collected by a different navigator, provided they too had followed the self-same instructions. We can see here one expression of Jan Golinski's point that disciplining as a form of scientific conduct rather than simply a route to subject definition not only provided instruction, but also controlled participants' behaviour.[17] It was not the chronometer on its own that thus achieved the accumulation of accurate data to improve hydrography. Rather it was, a consequence of what Porter termed 'mechanical objectivity': individuals were shaped and guided by the standardised rules.[18] Owen's instruction meant that navigators could bypass 'disciplinary objectivity', what in the early case of chronometer use was limited to astronomers and scientific servicemen.[19]

Data collection and astronomical accountancy

Practical chronometry involved more than just the daily winding of the chronometers and the recording of the results following the chronometer's application. The examination of navigational notebooks has shown that the process of navigation with chronometers was not as straightforward as is often assumed. Officers kept track of their position using dead reckoning, chronometers and astronomical observations. Although a logbook might present a longitude 'by chronometer' or by 'lunars', these navigational notebooks show how

[16] Stevin Shapin, 'Here and Everywhere: Sociology of Scientific Knowledge', *Annual Review of Sociology*, 21, (1995), pp. 289-321; Innes M. Keighren, Charles W. J. Withers, Bill Bell, 'Writing the Truth, Claims to Credibility in Exploration and Narrative', in: *Travels into Print: Exploration, Writing, and Publishing with John Murray, 1773-1859*, (London: University of Chicago Press, 2015), p. 99
[17] Jan Golinski, *Making Natural Knowledge: Constructivism and the History of Science*, (Cambridge: Cambridge University Press, 1998), p. 69
[18] Theodore M. Porter, *Trust in Numbers, The Pursuit of Objectivity in Science and Public Life*, (Chichester: Princeton University Press, 1995)
[19] Ibid, p. 3-4

interwoven and interdependent these outcomes could be. This was because a chronometric longitude was often brought to noon by dead reckoning and the rates that were applied had been calculated using lunar observations. To do this, officers kept written records which could be recalculated and corrected at a later date. Astronomical observations were crucial therefore for longitude determinations and record keeping was fundamental in keeping track of this.

William Parry's Arctic commands provided a valuable case study to show how these methods varied between each expedition and how the methods used were tied to the beliefs and capabilities of the accompanying astronomer. Observations made by previous observers were constantly referred to if possible. Simon Werrett has demonstrated, for instance, how Russian navigators referred to Captain Cook's measurements of latitude and longitude as a standard, against which their own measurements could be validated.[20] This research has also confirmed this practice amongst British naval officers, who not only referred to Cook, but to any other determinations which could help verify their results. Edward Sabine used Captain Capel's determination of the longitude of Rockall, as he considered this to be more reliable than that measured by the chronometers of the *Hecla*, using the rates ascribed to them. In this manner, navigation was not a 'one-off' measurement but a constant negotiation, between the methods applied on board ship (dead reckoning, chronometers and lunar observations, as George Fisher's navigational notebooks have shown) and through comparison to astronomical and chronometric determinations made by other officers. Comparisons with other determinations reveal reflections on why one measurement was considered more accurate than another and could vary as a result of the competence of the officer, the perceived quality of the instruments, or the astronomical methods applied.

[20] Simon Werrett, ''Perfectly Correct': Russian Navigators and the Royal Navy', in: *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds, (Basingstoke and New York: Palgrave Macmillan, 2016), pp. 111-133

Uncertainty remained a constant factor in navigation, even after the adoption of chronometers.

This thesis has shown that officers carrying and using several instruments spent considerable time comparing the times between the instruments and noting the differences recorded. This provided a check on the chronometers when astronomical observations were not available. Officers used these tables alongside shore-based astronomical observations, for the selection of chronometers that would determine a chronometric measurement, and as a basis for calculating the corrections that were required. This was a substantial part of chronometric practice and one that required additional skills, notably the 'eye and ear' method applied by astronomers in observatories. In addition to this practical method of observation and comparison, the methods of data collection known as 'keeping the books' reflected those practised in observatories.[21] This is evident in the attempts to standardise the calculations, and in the reductions of the results. Using many different chronometers where that was possible, several officers took multiple observations and applied their average. Officers who demonstrated that they could perform, record and analyse their data could claim credibility with respect both to the practices themselves and to the results. The astronomical accountancy that William Ashworth identified in the Royal Astronomical Society can also be found in these developing practices at sea.[22]

If one conclusion can be drawn from chronometric longitudes it is that no two determinations were ever simply the same. Agreement had to be reached. It was not until this agreement was reached that hydrography and, by extension, navigation, could benefit from the introduction of chronometers. Initially, this agreement was reached at sea, as

[21] Simon Schaffer, 'Keeping the Books at Paramatta Observatory', in: *The Heavens on Earth: Observatories and Astronomy in Nineteenth-Century Science and Culture*, David Aubin, Charlotte Bigg and H. Otto Sibum, eds. (Durham: Duke University Press, 2010), pp. 118-147

[22] William J. Ashworth, 'The Calculating Eye: Baily, Herschel, Babbage and the Business of Astronomy', *British Journal for the History of Science*, 27, (1994), p. 411

officers collated, organised and analysed the data they produced. This speaks to Theodore Porter's concept of quantitative objectivity and the idea of a 'social basis of authority' embodied in these officers.[23] Operating as fellows of the Royal Society and, closely connected as they were with the Board of Longitude, the Pendulum Committee and with other learned bodies, these officers had the authority to use these instruments in order to make judgements concerning their accuracy. In time, these would become stabilised values, or facts of longitude. Raper's list of longitudes that he urged navigators to adopt and adhere to were based on these singular voyages, together with similar expeditions conducted by French, Spanish and Russian authorities. This data, analysed and interpreted by officers at sea, reveals the invisible work involved in these naval officers' contribution towards a global system of reference points used in hydrography.

Withers has revealed the complex historical geographies of the prime meridian as a global point of reference, this thesis has examined the importance of reference meridians and how these were adopted in publications and on charts and therefore played a role in practice.[24] This also points to clear hierarchies in methods, where only astronomical observations could provide absolute longitudes and chronometers could contribute to relative longitudes. This is again to return to the dependence on astronomy, as instead of observatories, officers could now use these reference meridians to calibrate their chronometers. These meridians were points across the globe that had been determined by 'unimpugnable astronomical observations', as Henry Raper termed 'secondary meridians'.[25] These absolute positions were determined astronomically and served as reference meridians for surveys and chronometric determinations. Meridian voyages, hardly mentioned within

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[23] Porter, *Trust in Numbers*, p. 6

[24] Charles W. J. Withers, *Zero Degrees, Geographies of the Prime Meridian,* (Cambridge, Massachusetts: Harvard University Press, 2017)

[25] Henry Raper, 'Remarks on the Mode of Determining Longitude', *Nautical Magazine,* May, (1839) p. 320

histories of the chronometer or even in navigation, became an important tool in the measurements of relative longitudes, and would result in Charles F. Shadwell's manual on the management of chronometers and the measurement of meridian distances. Shadwell's manual reflected the practices of the voyages studied in this thesis and drew heavily on publications by Richard Owen and by Henry Raper.

Place was important here, as the observer was required to describe the spot where the observations were made so that the exact location could be revisited for use by other officers. Raper himself had negotiated these points of longitude, by examining, processing, and seeking agreement between the data collected by the Hydrographic Office. Whether the position was correct or not in terms of any absolute precision was not the point: rather, by agreeing these points, consistency led to uniformity of practice in hydrography. In addition to these secondary reference points, Raper called on navigators to adopt his list of longitudinal positions of principal maritime points. These proved important for simplifying the method of determining the rate and error of chronometers and would lead to the establishment of time signals. Longitude was thus constructed through processes of agreement. These established reference points across the globe enabled officers to calibrate their instruments by agreed standards which also led to uniformity in the collection and comparison of data. As such, uniformity and accuracy were an administrative achievement.[26]

The future of chronometry

There is more scope yet to broaden our understanding of how navigational manuals did or did not assist in the practical training in the use of these methods. Here, I have examined how they may have been used by Royal Naval officers whose education took part mainly on

[26] Theodore M. Porter, *Trust in Numbers, The Pursuit of Objectivity in Science and Public Life*, (Chichester: Princeton University Press, 1995), p. 14

board ship. This research is thus limited to a small group who had access to instruments and training that others did not. Additional research, where the sources permit, might reveal similar or different patterns in general naval voyages, within the merchant marine, or at a later period. There is some evidence to suggest that ordinary watches may have been used more widely at sea than chronometers, as late eighteenth-century navigation manuals often described how to rate a watch and determine the time in various sections relating to astronomical observations. Not until the early nineteenth century were these included under the heading 'longitude by timekeeper'. Additional research should extend to the mid-nineteenth century, to further our understanding of how chronometry became embedded in routine navigational practice, which continued to evolve. Position line navigation, for instance, which allowed the simultaneous calculation of latitude and longitude, was first published in 1843 by Captain Thomas Hubbard and was gradually adopted in the decades that followed. The influence of this new method on chronometric instruction and practice deserves more attention.

The focus of this thesis has been on a small number of case studies, yet the scope of my argument has a broader reach. It is possible that further insights might come from narrowing the focus. For example, a focus on one or two naval officers' educational background and practical training could tell us more about how one individual came to use these instruments in their particular ways. At the same time, and where it would be possible to do so, an instrument biography, that is, examining one chronometer through its use on different voyages, its repair, maintenance, the data it produced and its life post-retirement, would greatly enhance our understanding of different practices and their implications.[27] Such

[27] See for example the following chapter: Eugene Rae, Catherine Souch and Charles W. J. Withers, ''Instruments in the Hands of Others': The Life and Liveliness of Instruments of British Geographical Exploration, *c.*1860-.1930', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds. (Abingdon: Routledge, 2016), pp. 139-159

a biography would be critically dependent upon the survival of the necessary sources. The examination of the data produced would benefit from a more detailed account of how each trace of practice relates to another, how logbooks were constructed from a multitude of observers, observations and calculations, and what we can learn from the results there recorded.

In this thesis, I have explored the method of meridian distances that was employed by John Lewis Tiarks, Henry Foster and Robert Fitzroy. This principally national focus could be extended towards an international perspective to examine these determinations in relation to those made, for example, by the Russian General Schubert who established longitudes in the Baltic using 56 chronometers in 1833, and by Admiral Adam Johann von Krusenstern, who applied the method between 1803 and 1806, or by the French Captain Guattier du Parc, who measured chronometric distances in the Mediterranean and Black Sea. The advent of steam allowed the process to be applied more specifically to this aim, though no research up to date has examined how this influenced practice.

The final chapter of this thesis began with an examination of Henry Raper's call in 1839 to agree the reference meridians to which naval officers should refer their measurements. A decade earlier, the first time-signal had been trialled in Portsmouth. Our understanding of naval chronometry, technology, and science at sea would be enhanced through more in-depth research into how these were established in relation to the continuing role of the observatory. There is still more to be gained by examining how this influenced the practice of chronometry at sea, the trust that was placed in instruments, method and the production of data, and in the application in chronometry for routine navigation.

This thesis has also touched upon, but not explored in detail, the collaborative nature of research into chronometers, both at sea and on land. In his position as Astronomer Royal between 1835 and 1881, George Airy oversaw land and sea-based trials to understand how external factors influenced chronometers. Hydrographer Francis Beaufort oversaw sea-based trials by ordering specific guidelines to be followed by surveyors and requested the results to be reported back to him. Here, again further research might be possible to see how their work extended or differed from the Premium Trials of the 1820s. Finally, a growing overseas market for chronometers was appearing, where businesses would sell, repair and service instruments. It is clear from this research that these services were engaged with, and that it affected the status of the instruments. If chronometry was a 'thrifty science' in the sense of instruments' repair and the contingencies of practice, that too would merit greater attention.[28]

A historical geography of the chronometer

This thesis has made contributions to the historical geographies of science, the histories of navigation and to the histories of chronometry by emphasising the chronometer in action. It has done so through a focus on the places in which chronometry was practised, the individuals who used the chronometers, and the regulations, instructions and institutions that guided the behaviour of the chronometers and their users.

By examining the use of chronometers in the period following the end of the Napoleonic Wars from 1815, I have built on and contributed to research that has examined the changing role of naval officers and the emphasis of scientific practice at sea. Others have shown how this led to standardised methods of measurement, the use of precision instruments, the collection of data and the presentation of data in numerical, tabulated forms.[29] Drawing on research within the historical geographies of science, I have contributed

[28] Simon Werrett, *Thrifty Science: Making the Most of Materials in the History of Experiment*, (Chicago: The University of Chicago Press, 2019);

[29] Randolph Cock, 'Scientific Servicemen in the Royal Navy and the Professionalisation of Science 1816-1855', in: *Science and Beliefs: From Natural Philosophy to Natural Science 1700-1900*, David M. Knight, and Matthew D. Eddy, eds, (Aldershot: Ashgate 2005), p. 96

to our understanding of the 'relationships between science, technology, and method in terms of individual disciplinary formation'.[30] This thesis has shown how in relation to chronometry, this was still work in process, since, by the 1840s, there was yet more work to be done to ensure standard practices were adopted and to establish the necessary networks to allow this disciplinary formation to take shape.

This thesis has also contributed to the geography of the chronometer, and examined the places where longitude was constructed. These places, whether evident in Foster's Deception Island, or the Consul's garden in Funchal, were vital to constructions of longitude: they allowed users to check, calibrate, and correct their instruments. Chronometers are often seen as placeless, a device or mechanism that simply provided the time, regardless of where they were used. I have shown that this was not the case, and that the practice of chronometry was in reality rooted in a series of locations; on board ship, on bumboats, on shore and in observatories. The methods of their use bore the marks of these locations.[31] These findings confirm the research of Miller and Werrett, who also argue that instruments and methods were used together and in specific places depending on circumstances.[32] This thesis has shown exactly how this was the case and what mechanisms were employed to construct knowledge from these contingent practices. Following Simon Naylor's argument in relation to meteorology at sea, naval chronometry, like meteorology, transformed from an 'informal even idiosyncratic, culture of inquiry' to the uniform use of instruments with 'prescribed

[30] Fraser MacDonald and Charles W. J. Withers, 'Introduction: Geography, Technology and Instruments of Exploration', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds, (Abingdon: Routledge, 2016), p. 7

[31] Heike Jöns, David N. Livingstone, and Peter Meusburger, 'Interdisciplinary Geographies of Science', in: *Geographies of Science, Knowledge and Space, Volume 3*, Peter Meusburger, David N. Livingstone, Heike Jöns, eds, (Dordrecht: Springer, 2010), pp. ix-xvii

[32] David Phillip Miller, 'Longitude Networks on Land and Sea', pp. 223-247 and Werrett, ''Perfectly Correct': Russian Navigators and the Royal Navy', pp. 111-133, in: *Navigational Enterprises in Europe and its Empires, 1730-1850*, Richard Dunn and Rebekah Higgitt, eds, (Basingstoke and New York: Palgrave Macmillan, 2016)

observations and practices'.[33] This thesis has also contributed to scholarship which examines the ship as site of scientific enquiry and has shown how these experimental sites contributed to practices of standardised regimes of practice.

A further contribution of this research demonstrates the importance of data collection and its management. With these findings, the thesis contributes to the history of science and technology, the history of navigation and the history of the chronometer as no other study to date has examined the role, nor the implications of this aspect of chronometry. These practices developed alongside, and were shaped by, the expanding role of the state, the Admiralty and the scientific societies of the nineteenth century. These data practices at sea reveal how officers dealt with uncertainty, established authority and trust in their methods and helped navigational knowledge circulate on a larger scale. One further contribution of this work is that of methodology. I have demonstrated the value of close reading of navigational notebooks, scribbled calculations, calculated data and tabulated numerical outcomes for revealing daily practices at sea. While it is not uncommon to see these documents described as topic, I have shown how valuable they are as resource for understanding otherwise undescribed aspects of chronometry.

I have contributed to the history of science and technology by drawing on current research and approaches which have shown how chronometers were used in the pursuit of longitude. The evidence presented has shown how chronometers, alongside astronomical observations, constructed and constituted longitude. Informed by Porter's work concerning trust in numbers, I have shown how quantitative authority was achieved in the pursuit of longitude.[34] The pursuit of chronometry at sea became linked to the 'right moral habits' that

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[33] Simon Naylor, 'Weather Instruments all at Sea: Meteorology and the Royal Navy in the Nineteenth Century', *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. J. Withers, eds, (Abingdon: Routledge, 2016), p. 78

[34] Theodore M. Porter, *Trust in Numbers, The Pursuit of Objectivity in Science and Public Life*, (Chichester: Princeton University Press, 1995), pp. 3-8

Schaffer has described in nineteenth-century observatories.[35] Drawing on Simon Schaffer's analyses of the division of labour in observatories and the disciplining of the recorder, I have shown how 'disciplinary regulation' in chronometry was transferred from the observatory to the ship.[36] As Eóin Phillips has demonstrated, this process was underway in the late eighteenth century, and continued on nineteenth-century voyages.[37] This thesis has shown how Royal Navy officers were increasingly disciplined through observatory practices. This was achieved through standardised processes of observing, of numerical reduction and record keeping, and through instructions on the management of chronometers themselves. Observatory practices guided the process of observing, calculating and reducing the data: the Hydrographic Office collected, sorted and negotiated the outcomes. Henry Raper himself commented on the similarities between astronomy and hydrography: 'In fact hydrography has now arrived at a phase corresponding to that of Astronomy, at which the positions of the smaller stars, instead of being made the object of direct observations, are inferred with more convenience and precision from comparison with a few fundamental stars'.[38] Gradually, points of longitude became stabilised values represented in tables, sailing directions, charts and on maps. Ultimately, this instruction and standardisation helped to control the performance of the devices and the officers. The making of chronometric longitude was the result of processes of disciplinary formation, social negotiations and administrative practices at sea and on land.

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[35] Simon Schaffer, 'Astronomers Mark Time: Discipline and the Personal Equation', *Science in Context,* 2, (1988), p. 119

[36] Simon Schaffer, 'Astronomers Mark Time: Discipline and the Personal Equation', *Science in Context,* 2, (1988), p. 119

[37] Eóin Phillips, 'Instrumenting Order: Longitude, Seamen and Astronomers', in: *Geography, Technology and Instruments of Exploration*, Fraser MacDonald and Charles W. F. Withers, eds, (Abingdon: Routledge, 2016), pp. 37-55

[38] Henry Raper, 'On the Necessity of Adopting Secondary Meridians', *Nautical* Magazine, June, (1839), p. 402

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RGO 14: Papers of the Board of Longitude

NMM: *National Maritime Museum, Greenwich, UK*

FIS: Papers of Reverend George Fisher, (Astronomer), 1794-1873,

STK: Papers of Admiral John Lort Stokes, 1812-1885

PWDRO: *Plymouth and West Devon Record Office*

581/18: Edward Sabine, Geophysicist

RS: *Royal Society, London, UK*

MS: Manuscripts General

CMB: Committee Minute Books of the Royal Society

SPRI: *Scott Polar Research Institute, Cambridge, UK*

GB 15: Sir William Edward Parry Collection

GB 15: Edward Belcher Collection

TNA: *The National Archives, Richmond, UK*

ADM/1: Admiralty, and Ministry of Defence, Navy Department: Correspondence and Papers

ADM/3: Admiralty: Minutes

ADM/12: Admiralty: Digests and Indexes

ADM/55: Admiralty: Supplementary Logs and Journals of Ships on Exploration

BJ/3: Sir Edward Sabine: Correspondence and Papers

UKHO: *United Kingdom Hydrographic Office, Taunton, UK*

Survey Data Books: Astronomical Observation Books

Survey Data Books: Miscellaneous Books

MLP: Miscellaneous Letters and Papers

MP: Miscellaneous Papers

OD: Original Documents

LP: Letters Prior to 1857

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